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COMPUTER-BASED MAINTENANCE AIDS FOR TECHNICIANS: PROJECT FINAL REPORT

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This report summarizes a research and development program conducted by the Air Force Human Resources Laboratory to develop the technology to present maintenance technical data on a computer-based system. Several major efforts were completed including two feasibility studies, the development of two prototype systems to support intermediate level maintenance, and the development of a portable computer system for presentation of technical data for on-equipment maintenance.

The efforts have demonstrated that the presentation of technical data in this manner is feasible and that an automated system has the potential to improve performance and reduce the costs of maintaining the Air Force technical order system. In addition, effective man/machine-interface techniques, data presentation techniques, and computer hardware and software requirements were developed. The results of each of the efforts are described, and recommendations for the development of automated technical data presentation systems are provided.

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SUMMARY

Since 1976, the Air Force Human Resources Laboratory has conducted research and development (R&D) to develop the technology to present maintenance technical data on a computer-based system. Several major efforts have been completed including two feasibility studies, the development of two prototype systems to support intermediate level maintenance, and the development of a portable computer system for presentation of technical data for on-equipment maintenance. The R&D has included both laboratory studies to develop the required technologies and tests of the prototype systems under realistic field conditions in order to ensure that the systems satisfactorily meet the needs of the users.

The efforts have demonstrated that the presentation of maintenance technical data on a computer-based system is feasible and that an automated system has the potential to improve performance and reduce the costs of maintaining the Air Force technical order system. In addition, effective man/machine-interface techniques, data presentation techniques, and draft specifications for computer hardware and software were developed. The results of each of the efforts are described, and recommendations for the development of automated technical data presentation systems for operational use are provided.

PREFACE

This report summarizes R&D accomplished under Project 2362, Computer-based Maintenance Aids for Technicians. The objectives of the research were to develop the technology to present technical data on an automated technical data system and to develop and evaluate prototype systems for intermediate-level and on-equipment maintenance. The work built upon the results of a feasibility study conducted with Laboratory Director's Funds, which is also described in the report. The work was sponsored by the Logistics and Human Factors Division of the Air Force Human Resources Laboratory. Both in-house and contractual efforts were accomplished.

The report describes work accomplished under five work units. The work units and key Government and contractor personnel are listed below:

ILIR-00-34, Human Factors Study of the Feasibility of an Automated Technical Order System. Key Government Personnel: Mr. John J. K. Klesch and Ms. Wendy B. Campbell. Key Contractor Personnel: Dr. Thomas W. Frazier and Mr. Michael K. O'Heeron, Behavioral Technology Consultants, Inc.

2362-00-01, Optimal Formats for an Automated Technical Order System. Key Government Personnel: Ms. Wendy B. Campbell and Ms. Frances A. Greene. Key Contractor Personnel: Dr. Thomas W. Frazier, Dr. J. Thomas Roth, and Mr. S. Y. Huang, Behavioral Technology Corporation.

2362-00-02, Development and Evaluation of a Prototype Computer-based Maintenance Aids System. Key Government Personnel: Ms. Wendy B. Campbell, Ms. Frances A. Greene, and Dr. Donald L. Thomas. Key Contractor Personnel: Mr. Walter Holmes, and Mr. James Mitchell, Unified Industries, Inc.; and Mr. G. Richard Hatterick, BioTechnology, Inc.

2362-00-03, Computer-based Maintenance Aids System. Key Government Personnel: Mr. David R. Gunning, Ms. Barbara L. Masquelier, Dr. Donald L. Thomas, Lt Jeffery D. Clay, Major Paul Condit, and Mr. Timothy Hansell. Key Contractor Personnel: Mr. Perry Lanxner, Rockwell International; Dr. Alice Agin, Dr. Richard Funk, Ms. Jane Herman, Ms. Pat Newlands, Hughes Aircraft Company; and Mr. G. Richard Hatterick, BioTechnology, Inc.

2362-00-04, Portable Computer-based Maintenance Aids System. Key Government Personnel: Capt Stanley J. Collins, Lt Dean Orrell, Ms. Gail A. Hudson, Mr. Timothy Hansell, and Capt Michael J. Seus. Key Contractor Personnel: Mr. Roy LeCrone, Mr. Mike Darnold, Mr. William Higginbottom, and Mr. Steve Werner, Boeing Military Airplane Company.

Many individuals have made significant contributions to the work accomplished under the project. Overall direction was provided by Mr. Robert C. Johnson, Chief, Combat Logistics Branch. The following personnel have served as Project 2362 Program Manager during the 11-year history of the project: Mr. John J. K. Klesch, Ms. Wendy B. Campbell, Ms. Frances A. Green, Dr. Donald L. Thomas, Mr. David R. Gunning, Capt Stanley J. Collins, Ms. Barbara L. Masquelier, and Lt Jeffery D. Clay.

In addition to the Government personnel listed above, several personnel from the Strategic Air Command have made significant contributions to the project. Particular appreciation is expressed to:

Major Mike Mull and CMSgt Fred Sterling, HQ SAC, for their assistance in arranging for technicians to participate in the field tests.

Personnel of the 55th Reconnaissance Wing, Radar Shop, Offutt AFB, NE, for their assistance in the field test of the first prototype system.

Personnel of the 305th Air Refueling Wing, Radar Shop, Grissom AFB, IN, for their assistance in the field test of the first prototype system.

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COMPUTER-BASED MAINTENANCE AIDS FOR TECHNICIANS: PROJECT FINAL REPORT

I. INTRODUCTION

Since 1976, the Air Force Human Resources Laboratory (AFHRL) has conducted research and development (R&D) to develop the technology for the presentation of technical data on an automated system. The research was initiated in recognition of the potential of an automated technical data system to improve performance of maintenance personnel and reduce the cost of maintaining the Air Force technical data system. The emphasis in conducting the R&D was placed upon designing technical data presentation techniques and procedures tailored to meet the technicians' needs and make it easier for them to do their job. Emphasis was placed upon developing data access techniques which make it easy to locate needed information and developing presentation formats which make it easy for them to use the information. Experienced maintenance personnel from operational maintenance units were involved in all phases of the program (as consultants and test subjects) to ensure that the needs of the maintenance technician are met and that the techniques developed are suitable for use in actual maintenance operations.

A laboratory demonstration, two prototype systems for intermediate level maintenance, and a prototype system for on-equipment maintenance were developed. Although the prototype systems were not intended for actual operational implementation, they were designed to fully test all required functions and to accurately simulate an operational system. The prototypes were tested in maintenance shops of operational units to provide realistic evaluations of the systems under operational conditions. Specifications for technical data content and system hardware and software for use in developing systems for operational use were developed on the basis of knowledge gained from development of the prototypes and from experience gained in the field tests.

The majority of the work was conducted under Project 2362, Computer-based Maintenance Aids for Technicians. Five major efforts and several smaller efforts have been conducted under the project. The results of these efforts are summarized in this report.

Background

It has been recognized for many years that conventional technical orders (TOs) used to support maintenance personnel are often incomplete, poorly organized, and difficult to use. For many years, AFHRL conducted an R&D program to develop better technical data for use by maintenance personnel. The emphasis was placed upon developing technical data which are easy to use and provide in one place all of the information that the technician needs. The major product of this research was the fully proceduralized job performance aid (FPJPA). FPJPAs provided the technician with step-by-step instructions for performing assigned tasks. FPJPAs are based upon a thorough task analysis to ensure that the procedures are complete, accurate, effective, and suited to the skills of the intended user.

Available research efforts indicate that the use of FPJPAs can result in significant improvements in performance and are well received by technicians. One problem associated with FPJPAs is that they require many more pages to cover a system than do TOs. This, plus the increasing complexity of modern aircraft (and the resulting increase in technical data requirements), makes it essential that a more cost-effective method of maintaining the TO system be found.

Automation of the TO system appeared to be the logical solution to the problem. In addition, the capabilities offered by the computer appeared to provide the potential for even more effective technical data and further enhancements in performance. For these reasons, Project 2362 was initiated in 1976 to develop the technology for the presentation of technical data via a computer system display. At approximately the same time, the Automated Technical Order System (ATOS) project was initiated by the Air Force Logistics Command to automate the production and updating of technical data. The long-range plan was for the two programs to converge in the mid-1980s so that the presentation system technology developed by AFHRL would be incorporated as the presentation portion of the ATOS for operational application.

Objective

As stated in the Program Management Directive, the objective of Project 2362 was to:

> ...develop a prototype computer-based technical data system to facilitate the productivity of Air Force maintenance personnel. The system will provide information at the work site to guide technicians' performance. Attention will be given to determining the basic needs of technicians for information and the characteristics of a hardware and software system to provide that information. A major consideration will be the efficiency and effectiveness of the man-computer (software and hardware) interaction. Initial efforts will involve clarifying the technicians' needs for information and an assessment of the hardware and software to meet those needs. With special attention to problems of interface, utilization and acceptance, a limited prototype system will be developed and demonstrated/evaluated.

The individual R&D efforts conducted to achieve the project objectives are briefly described in the following paragraphs. The efforts are described in detail in Sections II through VI. Recommendations for future automated technical data presentation systems (ATDPS) and for further research are provided in Section VII.

Approach

The basic approach taken to achieve the project objective was to first conduct feasibility studies to establish the feasibility of an ATDPS, identify the basic features which should be provided by such a system, develop and evaluate prototype systems, and develop draft specifications for use in

developing and procuring systems for operational use. Two feasibility studies were accomplished and three prototype systems were developed. Evaluations of two of the prototypes were performed. An evaluation of the third prototype is scheduled for the Spring of 1988.

Project Results

Feasibility Studies

Historically, the first attempt to automate the presentation of technical data by AFHRL was accomplished as part of the earlier FPJPA research (Project 1194). The objectives of this effort were to provide a means:

1. For ready retrieval of data organized in tree form by personnel having little or no experience with computers;

2. For rapid updating of data from a remote terminal;

3. For batch storage, updating, and editing of data; and

4. For allowing experimental building of data files from a remote terminal by personnel having minimal or no experience with computers.

Existing software packages with the capability to handle data with extensive branching were adapted for the study. The software was installed on a mainframe computer system (CDC 6600) at the Aeronautical Systems Division Computer Center. Data prepared in a fully proceduralized troubleshooting format were input to the system. The system was then tested by having personnel with limited computer experience retrieve data from the system using a remote terminal (teletype). Although the basic goals of the project were achieved, communication with the computer system via the terminal was too slow for practical use. Also, the system was not able to handle graphics. It was concluded that the basic concept of computer retrieval and presentation of data had potential but that further developments in computer hardware and software were required for effective presentation of technical data for operational use.

The effort is described in detail in Colwell (1971), Colwell and Risk (1971), and Colwell, Risk, and Reed (1971).

Two feasibility studies were conducted to systematically examine the feasibility of an ATDPS and to develop a preliminary system design. The studies were conducted under contract by Behavioral Technology Consultants, Inc. (F33615-77-C-0043) and Behavioral Technology Corporation (Contract F33615-78-C-0030).[1]

[1]Behavioral Technology Corporation was established as a result of a reorganization of Behavioral Technology Consultants, Inc. The ownership and key personnel of the two companies were the same.

The objectives of the feasibility studies were to systematically examine the feasibility of creating and implementing an ATDPS, analyze and establish the requirements for information to be presented on the system, establish human factors requirements for the system, develop system design concepts for the system, and conduct a preliminary test of the design concepts and features developed.

The feasibility studies determined that the development of an ADTPS was feasible and that the development of such a system would have significant potential to improve Air Force maintenance operations. A basic system design was developed and given a preliminary test in a laboratory environment. Key system requirements proposed included:

1. The system should be designed for ease of use. It should provide the user with the capability to easily recall any desired information.

2. A special function keyboard should be provided to simplify interaction with the system. The special functions and keyboard should be designed to permit recall of any desired information with one or two keystrokes.

3. Procedural data should be prepared in a step-by-step format similar to that used for FPJPAs. The data should be provided in multiple levels of detail so that the user may select data designed to be compatible with his level of experience and training.

4. Easy access should be provided to "pools" of support information that the user may want to refer to while performing a task. Pool information may include system information (such as theory of operation, system descriptions, and parts information) or other support information (such as how to set up test equipment).

The results of the Behavioral Technology feasibility studies are summarized in Section II.

Initial Prototype Development

A contract was awarded to Unified Industries, Inc. (UII) in September 1978 to develop and evaluate a full-scale prototype ATDPS for intermediate level maintenance. Initial work on this effort focused upon the development of the human factors and technical data requirements for the system. Man/machine interface (MMI) techniques (including a function keyboard design) and data presentation formats were developed. Work was initiated on the design of the hardware and software. However, it became necessary to terminate the contract before the system could actually be built. The decision to terminate the contract was made as a result of the addition of a requirement by the sponsor that the system must be deployable. The prototype system under development was designed for stationary use. Extensive modifications would have been necessary to make it deployable. It was determined to be in the best interests of the Government to terminate the contract.

Although the prototype was not completed, significant progress was made in defining the requirements for an ATDPS. The results of the work performed are discussed in detail in Section III.

Computer-based Maintenance Aids System (CMAS) Development and Evaluation

A second effort to develop an ATDPS prototype for intermediate level maintenance was established in 1982. A contract was awarded to Rockwell International (prime contractor) and Hughes Aircraft (subcontractor) for the development of the Computer-based Maintenance Aids System (known as CMAS I). Emphasis was placed upon developing human factors and data presentation requirements. A decision was made to use existing hardware and to adapt existing software for the effort, rather than procure/develop hardware and software specifically designed for the CMAS I. An analysis was made to determine requirements for a deployable system; however, no attempt was made to make the CMAS deployable.

The development of the CMAS I was based upon the earlier work accomplished in the feasibility studies and the UII effort. In addition, further analyses of technician information needs were made, and three design studies were accomplished to evaluate several design issues. Software originally developed for the Navy Technical Information Presentation System (NTIPS) was adapted and extended to meet the needs of the CMAS I. An available MODCOMP Model 7840 minicomputer system with a Rastertech color graphics terminal was used to host the CMAS.

The CMAS I was installed in an intermediate level avionics maintenance shop (Radar) at Offutt AFB, Nebraska, for evaluation. The evaluation revealed that the CMAS I did not successfully meet the goals of the program. The system failed to achieve acceptance by the users. The users' rejection of the system was primarily due to the extremely slow response time of the system (approximately 11 seconds to retrieve a typical procedural frame) and to several ineffective MMI techniques employed. Although the CMAS I effort was not a complete success, it did provide very valuable information for the development of the follow-on system.

The CMAS I effort is described in detail in Section IV.

CMAS II Development and Evaluation

The CMAS II effort was initiated to develop an ATDPS for intermediate level maintenance which did not have the weaknesses of the CMAS I and would be accepted and used by maintenance technicians. The CMAS II was developed in-house using available off-the-shelf hardware. Extensive modifications to existing software were made to provide the capabilities required for the system.

The Grid Compass Model 1139 microcomputer was selected as the hardware for the system. The CMAS II design incorporated many of the design features provided in the CMAS I. However, in developing the system, emphasis was placed upon improving the system response times, eliminating the cumbersome MMI techniques, and adding additional features to improve usability.

Technical data for a testbed system (the RT-728A receiver of the AN/APX-64, Identify Friend or Foe System) were reformatted and expanded. The data were then input to the computer, and the CMAS II was taken to Grissom AFB, Indiana,

for a field demonstration in June 1985. The CMAS II was tested by having experienced and inexperienced technicians use it to perform representative maintenance tasks. The tests demonstrated that the technicians could effectively perform maintenance using the system. Questionnaires and interviews indicated that the technicians liked the system and would like to see a similar system implemented for operational use. In addition to the Grissom test, a joint Air Force/Navy evaluation of the CMAS II was conducted by the Navy Personnel Research and Development Center (NPRDC). The system was evaluated using Air Force, Navy, and Marine technicians. The results were similar to those obtained at Grissom AFB. Following the CMAS II demonstration, system functional specifications for automated technical data systems and for technical data to be presented on the system were developed. The specifications were based primarily upon the CMAS II.

The CMAS II effort is described in detail in Section V.

Portable Computer-based Maintenance Aids System Development

The next step in the program was to extend the CMAS technology for on-equipment (flightline) maintenance. A small, rugged, lightweight computer system is needed for use on the flightline. A suitable portable computer system did not exist. Therefore, a contract was awarded to develop a portable computer-based maintenance aids system (PCMAS) designed specifically for the presentation of technical data for on-equipment maintenance. The contract was awarded to Boeing Military Airplane Company, Huntsville, Alabama, on 31 July 1985, to develop the system.

The design and fabrication of the initial PCMAS unit have been completed. The PCMAS is a semi-ruggedized portable computer designed for flightline use. It weighs 13 pounds and has dimensions of 12 x 15 x 3 inches. Technical data for presentation on the system are maintained in removable, 1-megabyte memory cartridges. The PCMAS is capable of operating on power from a battery pack, on power from the aircraft, on power from a ground power unit, or on standard commercial power (110 VAC). A keypad with eight programmable function keys, a numeric keypad, and cursor control keys are provided for interaction with the system. A voice activation capability is also provided. A built-in 1553 data bus board provides a capability to communicate directly with aircraft systems on aircraft equipped with a MIL-STD-1553 data bus. The PCMAS may be operated in a stand-alone mode or in conjunction with a workstation which provides a full keyboard, hard disk drive, printer, and additional communication capabilities. Software developed for the system includes a UNIX-based operating system and applications software for the presentation of technical data and for computer-based diagnostics.

Three prototype units were produced by Boeing. The units are presently being used in-house to develop additional applications and to modify the production software to correct some deficiencies. Starting in the spring of 1988, studies will be conducted to evaluate the PCMAS as a technical data presentation system, as a computer-based diagnostics aid, and as a device for presenting specialized technical data for aircraft battle damage assessment (ABDA).

Section VI presents a detailed description of the PCMAS.

Recommendations and Research Needs

The research described above provided a firm basis to develop recommendations for the development of automated technical data systems for operational use. Also, in evaluating the results of the studies, a number of issues have been identified which require further research. The recommendations developed and the research needs identified are discussed in Section VII.

Future Efforts

Although the Computer-based Maintenance Aids for Technicians project has officially ended, the Laboratory is continuing work in the automation of technical data and other types of information used by maintenance personnel. This work is being conducted under Project 2950, Integrated Maintenance Information System (IMIS). The IMIS program will include further development of techniques for presentation of technical data on an automated technical data system and the development of techniques for the automated creation of diagnostic routines. These techniques will be used in the development of the IMIS, which will integrate the following information systems: technical data presentation systems, automated diagnostics systems, automated maintenance management systems, computer-based training systems, and supply systems. The IMIS will make it possible for a technician to access any information required to do his job from one computer system using a common set of data access protocols. The program is described in Link, Von Holle, and Mason (1987).

II. FEASIBILITY STUDIES

By the mid-1970s, computer technology had advanced to the point that the use of computers for the storage and presentation of technical data had become feasible and practical. Work was initiated to establish the feasibility of an automated technical data presentation system and to develop a preliminary system design.

The initial contract in the CMAS program was awarded to Behavioral Technology Consultants, Inc. in 1976 for a study to examine the feasibility of a computer-based technical data system, to identify the human factors requirements for such a system, and to develop initial system design concepts. A follow-on contract was awarded to Behavioral Technology Corporation in 1977 to further develop the concepts. The overall goals of this work were to establish the feasibility of a CMAS and to conduct an initial "top-down" design of the system. The basic orientation of the system design process was to design the system from the viewpoint of the maintenance technician to ensure that it would fully support the user in the work place. The results of these studies are summarized in this section. The materials presented in this section are adapted from unpublished reports by Frazier, Campbell, and Kniess (1979) and Frazier, Huang, and Roth (1978).

Objectives

The objectives of the studies were:

1. To systematically examine the feasibility of creating and implementing a CMAS.

2. To analyze and establish the requirements for technical information to be presented on a CMAS.

3. To establish the human factors requirements for a CMAS system.

4. To develop system design concepts for presentation of technical information on a computer system to ensure technician acceptance, enhanced performance, and usability.

5. To conduct a preliminary test, in a laboratory environment, of the design concepts and features developed.

Approach

A four-phase effort was conducted to achieve the above objectives.

Phase I. Human Factors Requirements

The purpose of this phase was to examine the human factors requirements for a computer-based maintenance aiding system. This was accomplished by reviewing available MMI techniques, investigating previous research on improved technical data, reviewing relevant literature, and studying Air Force maintenance operations. As a result of this analysis, four specific problem areas were identified for detailed study. These were: (a) communication between the technician and the system; (b) content of textual materials; (c) content and management of stationary and animated graphics; and (d) formats for presentation of technical data. Each of these areas was systematically studied. Potential approaches and solutions were developed, refined, and incorporated into a preliminary system design for test on a laboratory system.

Phase II. Demonstrate Feasibility

The purpose of the second phase of the study was to demonstrate the feasibility of a computer-based maintenance aiding system and to test the preliminary system design in a laboratory environment. A small minicomputer system with the basic capabilities required to support a system for presenting automated technical data was assembled at the contractor's facility, and the necessary software was developed or procured. Technical data for representative tasks were entered in the system to provide a basis for evaluating the various MMI and data presentation techniques developed earlier.

Phase III. Evaluate Preliminary System

In this phase, additional technical data were developed for use in a more systematic evaluation of the system. The system was then tested using experienced technicians as subjects.

Phase IV. Develop System Design Requirements

In the final phase of the effort, the information gathered was synthesized to develop fundamental system design requirements and preliminary hardware and software specifications for a CMAS.

Findings

Phase I. Human Factors Requirements

The findings of Phase I are summarized below.

Criteria. The primary criteria, established at the start of the study, were that the computer-based maintenance aiding system must be easy to use and must effectively meet all of the technician's needs for information to do his job. The first task in this phase was to further define the usability criteria. The criteria developed provided the basis for evaluating all MMI techniques, data presentation techniques, and design considerations developed during the course of the study. Seven criteria were identified. The first five criteria were adapted from Chenzoff (1973). The last two were added by the researchers for this effort. The seven criteria were:

1. Accuracy - Data must be technically correct.

2. Understandability - Data must be easily understood by the user.

3. Retrievability - Required data must be easy to find.

4. Relevance - Data must meet user needs.

5. Completeness - Data must provide a technician with all of the information that he needs.

6. Portability - Data must be easy to carry and use.

7. Availability - Current data must be readily available in the work area.

An analysis was made of the problems encountered in meeting the above requirements using paper-based systems and the potential for a computer-based system to overcome these difficulties.

Man/Computer Dialog Design. The problem of how the technician interacts with the computer was analyzed. Two primary concerns were addressed: the nature of the man/machine interaction and the method used by the technician to enter the request to the system. With regard to the nature of interaction, system communication should be as natural as possible (i.e., similar to normal communication between humans) and should be positively reinforcing. Analysis of different user entry requests showed that requiring the technician to type in all necessary information would not be suitable since it is time-consuming and requires typing skills that the average technician does not have. Therefore, an alternate approach was developed which would let the technician

quickly enter the request without requiring special skills. The proposed solution used a special function panel--a "Dialog Generator Panel."

The proposed Dialog Generator Panel design provides 23 special function keys for entering requests to the computer. Use of the function keys allows the technician to enter a request with one keystroke in most cases and only a few keystrokes in others. Two types of functions are provided:

1. Non-referenced communication functions require only one keystroke. For example, the key OUTLINE SYSTEM FUNCTION can be used to retrieve a functional description of the system currently being maintained.

2. A referenced communication function requires the technician to press the key and a number indicating a selection. For example, pressing DEFINE and "1" would result in the system displaying an object presented on the screen and identified as "1."

The proposed special functions and their definitions are presented in Table 1.

Table 1. Proposed Function Keys

Function	Type[a]	Description
CORRECT ENTRY	N	Used to correct alphanumeric data entry that is to be logged in the system or used for retrieval of information choices from subsystem memory.
LIST FORMATS	N	Used for permitting the user to identify a choice among alternative types of information when menus are provided on the cathode-ray tube (CRT) screen.
STEP BACK	N	Used to retrieve the frame that appeared immediately prior.
OUTLINE TASK	N	Used to obtain a summary of the maintenance task at hand for preview purposes, prior to undertaking it.
OUTLINE SYSTEM	N	Permits retrieval of the functional data concerning the system/subsystem/equipment being worked upon.
DESCRIBE	R	Used when graphic portrayals are requested for such objects as parts, tools, subassemblies, etc.
OPERATE	R	Used for retrieving pseudoanimation sequences or textual descriptions of tool use.

Table 1. (Continued)

Function	Type[a]	Description
COMPLETE	N	Used to signify completion of task steps and completion of the overall task.
DEFINE	R	Used to retrieve definitions of special technical terms.
EXPLAIN	R	Used to obtain a verbal explanation where one is likely to be needed.
WHAT NEXT	N	Used to retrieve follow-on information whether expressed as a task step or in some other manner.
READY	N	Signals that the user is prepared to accept new information presented in sequential form.
LOCATE	R	Used to locate schematic descriptions and illustrated parts breakdowns where a specific item must be found or identified from a larger assembly of items.
YES	N	Used when the system is required to make a check requiring either a "yes" or "no" response.
NO	N	Used when the system is required to make a check requiring either a "yes" or "no" response.
SHOW HOW	R	Used to invoke a pseudoanimation procedure other than one that demonstrates tool use.
SIGNIFICANCE	R	Used to learn about crew or aircraft significance of a given fault or repair.
UNDERSTAND	N	Used to convey comprehension of frame contents to the system.
I WOULD LIKE	R	Used to communicate choices to the system.
CHECK	N	Used to identify the presence of checklist items or compliance with procedures listed in checklist form.
ZOOM	N	Permits scaling of screen contents to a desired size.

Table 1. (Concluded)

Function	Type[a]	Description
ROTATE/PERSPECTIVE	N	Used to obtain different view angles of a component, equipment, or other physical object.
COMPARE	R	Used to retrieve deductive materials that the user wants to have displayed simultaneously on the CRT screen.

[a]N indicates non-referenced communication; R indicates referenced communication.

Backlighting the keyboard was recommended so that only those keys currently active are lit. This approach was proposed in order to lessen the search time required to locate the desired function key.

Supervisor-Technician Discourse. The researchers believed that the impersonal, directive language used in conventional technical orders would have a negative impact on the technician's motivation to use the system. For this reason, it was recommended that the language used to state instructions presented on the system be similar to that used by a supervisor telling a technician how to do the task. An analysis was made of the language and phrasing of instructions used by supervisors in telling how to do a task. Recordings were made of communications between Air Force maintenance supervisors and technicians performing representative tasks. Analysis of the communications yielded a style of communications which could be used for presenting computerized technical data in a more "natural" fashion than used in technical orders. For example, the technical order might say, "Turn handle to left, remove RT Unit. Insert replacement RT Unit, turn handle to right." In the personalized style, the instruction would say, "Now, turn the handle to the left and pull the RT out. OK, now you are ready to put the new RT in. After it is in place, turn the handle to the right."

Technical Data Format Design. The Fully Proceduralized Job Performance Aid (FPJPA) approach developed by AFHRL (Joyce, Chenzoff, Mulligan, & Mallory, 1973) was used as the starting point in developing formats for presentation of data on a computer-based system. Analysis of the FPJPA format revealed several features which were recommended for incorporation in the automated system. The principal features proposed for retention were:

1. Dual-Level Presentation. The FPJPA dual-level feature presents information in both boldface and regular print. The regular print provides detailed instructions on how to do the task and is intended for technicians with limited experience on the task. The boldface print outlines the major steps for completing the task and is intended for the experienced technician who is fully qualified on the task and does not require the detailed instructions. The authors recommended that the dual-level concept be applied and extended to provide three or more levels of detail or "tracks" depending upon the complexity of the task. They noted that an automated system can make much better use of the concept since it can support any number of levels of detail.

A three-track approach was developed. The tracks would provide data at three levels of detail appropriate for experienced, average, and inexperienced technicians. It was suggested that three levels of detail are adequate for most tasks but that four or even five levels may be required for special circumstances. Examples of instruction frames presented in the three basic tracks are presented in Figures 1, 2, and 3. The Track 1 instructions (Figure 1) provide only critical information as reminders of critical steps, warnings, and cautions. These instructions are provided for highly experienced technicians who have performed the task many times. The Track 2 instructions (Figure 2) present information in the form of a checklist, with supporting graphics on call. These instructions are for technicians who have performed the task many times but are not yet "well experienced." The Track 3 instructions (Figure 3) provide detailed procedures supported by abundant graphics information. These instructions are intended for the inexperienced technician.

2. Use of Line Drawings. FPJPAs provide line drawings keyed to the instructions to help the technician locate referenced parts. Similar drawings were recommended for the automated system. It was pointed out that FPJPA drawings a usually very detailed, but that less-detailed drawings would be required automated presentation (to reduce storage requirements).

3. ation Instructions. FPJPAs provide a summary of information plies, warnings, cautions, etc.) required to perform a task at the of a procedure. This feature is similar to the Input Conditions of a standard Job Guide Manual. The authors proposed that, with an automated system, the information could be presented at points in the procedure where it would be the most beneficial.

```
REMOVE AND INSTALL THE ENGINE STARTER CONTROL VALVE     C-141A

                 •••••••••••••••••
                 • REPAIR NOTES •
                 •••••••••••••••••
[1] BE SURE TO CAP THE SMALL AIR TUBES TO KEEP DUST OUT OF THE STARTER.
[2] ALL NUTS SHOULD BE TORQUED TO 50-55 FOOT-POUNDS.
[3] SAFETY WIRE ALL NUTS AND ELECTRICAL FITTINGS.
[4] CAP ALL PORTS OPENED IN THE STARTER AND ENGINE.
[5] BE SURE TO REPLACE ALL REMOVED GASKETS AND O-RINGS
    WITH REPLACEMENTS FROM THE REPLACEMENT KIT.
[6] LUBRICATE ALL FITTINGS, GASKETS AND O-RINGS •BEFORE•
    INSTALLATION.

                 ••••••••••••••••••••••••
                 • SPECIAL REPAIR NOTE •
                 ••••••••••••••••••••••••

AFTER INSTALLING THE NEW STARTER CONTROL VALVE, C'ECK THE CLEARANCE
BETWEEN THE UPPER V-BAND COUPLING ON THE STARTER CONTROL VALVE
AND THE BLOWOUT DOOR HOUSING.

        THIS CLEARANCE MUST BE AT LEAST .250 INCHES
        TO AVOID MECHANICAL-ELECTRICAL INTERFERENCE
        WITH STARTER OPERATION.  ADJUST TO THIS CLEARANCE.
/////////////////////////////
AVAILABLE KEYS: LIST FORMATS.
   READY (ALL DONE WITH JOB)
/////////////////////////////
```

Figure 1. Example of Track 1 Frame for Remove and Replace Task.

REMOVE AND INSTALL THE ENGINE STARTER CONTROL VALVE

YOUR FIRST TASK IS TO REMOVE THE STARTER
CONTROL VALVE FROM THE ENGINE YOU ARE
WORKING ON.

I'LL SHOW YOU A SERIES OF STEPS, ONE AT A
TIME. WHEN YOU FINISH A STEP, LET ME
KNOW, AND I'LL PRESENT THE NEXT STEP
DESCRIPTION.

THE FIRST STEP IN THIS TASK IS TO:

DE-ENERGIZE THE STARTER ELECTRICAL CIRCUITS
FOR THE ENGINE YOU'RE WORKING ON

///////////////////////////
AVAILABLE KEYS: OUTLINE TASK,
STEP COMPLETE
///////////////////////////

Figure 2. Example of Track 2 Frame for Remove and Replace Task.

REMOVE AND INSTALL THE ENGINE STARTER CONTROL VALVE C-141A

OK. THE FIRST THING TO DO IS
TO REMOVE THE ENGINE STARTER
CONTROL VALVE.

I'LL SHOW YOU HOW TO REMOVE THE
THE VALVE, ONE STEP AT A TIME

THE FIRST STEP IN THE REMOVE IS :

OPEN AND TAG THE START AND
START IGNITION CIRCUIT BREAKER [1]
FOR THE ENGINE THAT YOU ARE
WORKING ON

LET ME KNOW WHEN YOU FINISH
A STEP, AND THEN I'LL
SHOW YOU THE NEXT STEP

///////////////////////////
AVAILABLE KEYS:
STEP COMPLETE
///////////////////////////

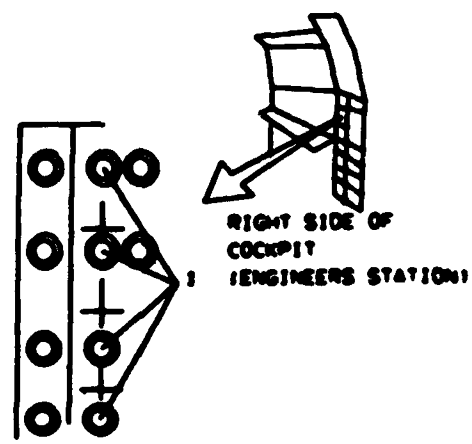


Figure 3. Example of Track 3 Frame for Remove and Replace Task.

4. Formats for Troubleshooting. For troubleshooting, the authors proposed using the FPJPA format for inexperienced technicians, a logic tree format for average-experience-level technicians, and a deductive troubleshooting aid format for highly experienced technicians. The deductive troubleshooting aid would provide only basic information needed to troubleshoot. The basic information would include schematics, wiring diagrams, and similar types of information.

Pool Concept. The use of pools of support information was also proposed. Pool information is defined as back-up information which may be made available at a given point in the procedure where it may be needed by some users. The pool concept is described as tailoring information to meet an individual's specific information needs. It provides a means for providing supplemental or remedial instructions for portions of a task that are unfamiliar. For example, if a technician is directed within a procedure to calibrate an oscilloscope but does not remember how, he would be able to call up a procedure from the "pool" on how to calibrate the scope. Several types of information were suggested as pool information.

1. Significance Information. Provides an explanation of the significance of the work being done in terms of flight safety and functional integrity.

2. Overview of Maintenance Task. Provides a preview summary of task to be performed.

3. Part, Supply, and Tool Descriptions. Provide information on parts, supplies, and tools including cross-references of serial and identification numbers. Graphics may be provided.

4. Use of Tools and Test Equipment. Provides reference information on the correct use of tools and test equipment.

5. Subsystem Functional Descriptions. Provide information on functions and operation of subsystems.

6. Diagrams and Schematics. Provide the appropriate diagrams and schematics for the specified equipment.

7. Preference Performance Descriptions. Provide information such as special terminology and vocabulary, basic maintenance procedures, etc.

Graphics Simplification. Examination of typical illustrations used in technical orders revealed that the illustrations are highly detailed. Due to the large amount of computer memory required to store detailed graphics, techniques are needed to reduce the detail and complexity of the graphics. An analysis of illustration requirements was made to identify methods to simplify graphics.

The analysis viewed graphics as combinations of discriminative and nondiscriminative stimuli. Discriminative stimuli provide a cue to the identification of an object. Nondiscriminative stimuli do not provide a cue to the identification of the object in question (although they might provide a cue to the identification of other objects on the graphic). Discriminative

stimuli provide useful information. Nondiscriminative cues provide no useful information for the task at hand. Therefore, graphics provided for the purpose of aiding the user in identifying components referenced in the text could be simplified by including only the discriminating stimuli and leaving out the nondiscriminating stimuli. Thus, a graphic illustrating a piece of equipment need include only enough detail (discriminating stimuli) to locate the item of concern. Other detail (nondiscriminating stimuli) can be eliminated from the graphic, saving both storage space and the time required to draw the detail on the screen.

Figure 4 demonstrates the application of this approach to graphics simplification. Graphic A is a drawing of an oscilloscope from the angle at which the user would view it. This graphic shows all of the key elements on the face of the oscilloscope, but not with the detail shown in the technical order. Graphic B shows a simplified illustration which might be used in support of an instruction to turn on the scope. It includes only the key geographical cues to show the approximate location on the scope and enough surrounding detail to pinpoint the specific component. Graphic C shows how a subsequent graphic might be used to locate another component of the same scope. Graphics B and C illustrate the fact that a stimuli may be a discriminating cue in one case and a nondiscriminating cue in another case. There appears to be no particular justification for presenting full detail of an equipment/assembly needed only for locator purposes.

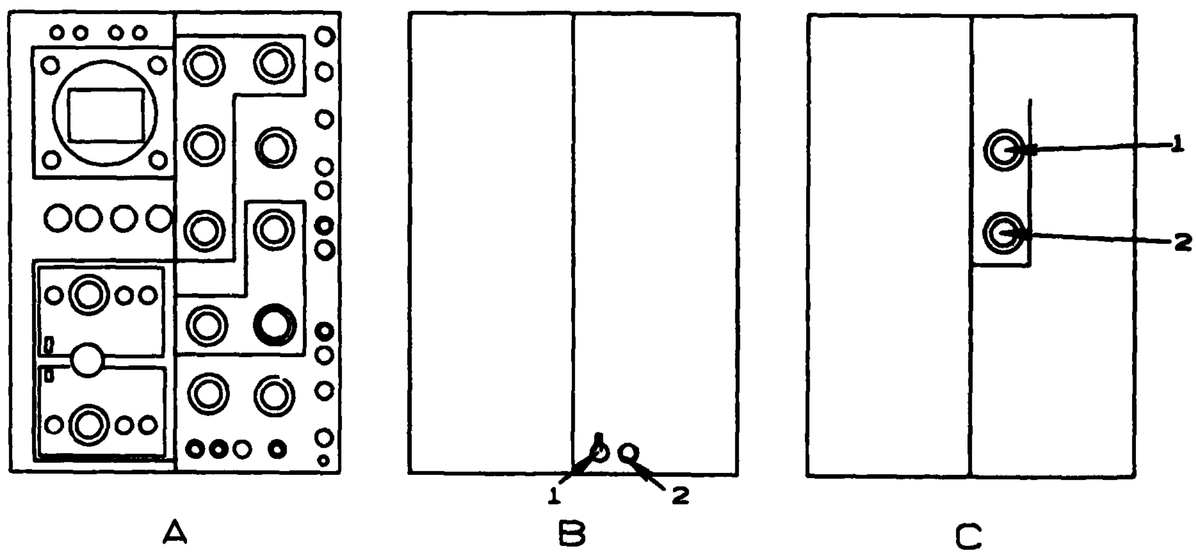


Figure 4. Example of Graphics Simplification Concept.

Frazier, Campbell, and Kniess (1979) noted that the use of computer graphics for presenting an illustrated parts breakdown (IPB) presents a special problem. The highly complex drawings require large amounts of core memory and require displays with very fast drawing speeds to prevent flicker. The precision and resolution of the display become important when displaying IPB graphics. For this reason, simplification of IPB graphics is essential.

Fine detail is more important in IPB graphics since small details may be important in discriminating small parts. An automated system should give the technician the capability to discriminate fine detail from several feet away. Zooming the illustration can be used to achieve maximum viewability. However, this may cause other desired detail to move out of the viewing area. For this reason, when the zoom feature is used, the technician must be able to control the degree of zoom to achieve the best combination of detail and viewing area. A joystick is suggested as a means of providing control.

Figure 5 illustrates an approach proposed for organizing a large complex graphic for computer display. For a complex assembly, the entire assembly is shown in limited detail. The user then has the option to select designated sections of the assembly for detailed viewing. This approach can provide a solution to the overcrowding of the graphics display while still providing the required detail without using the zoom technique. This approach is shown in Figures 6 and 7. Figure 6 shows a limited-detail view of the whole assembly. Figure 7 demonstrates how a more detailed view of a section of the overall assembly can be displayed.

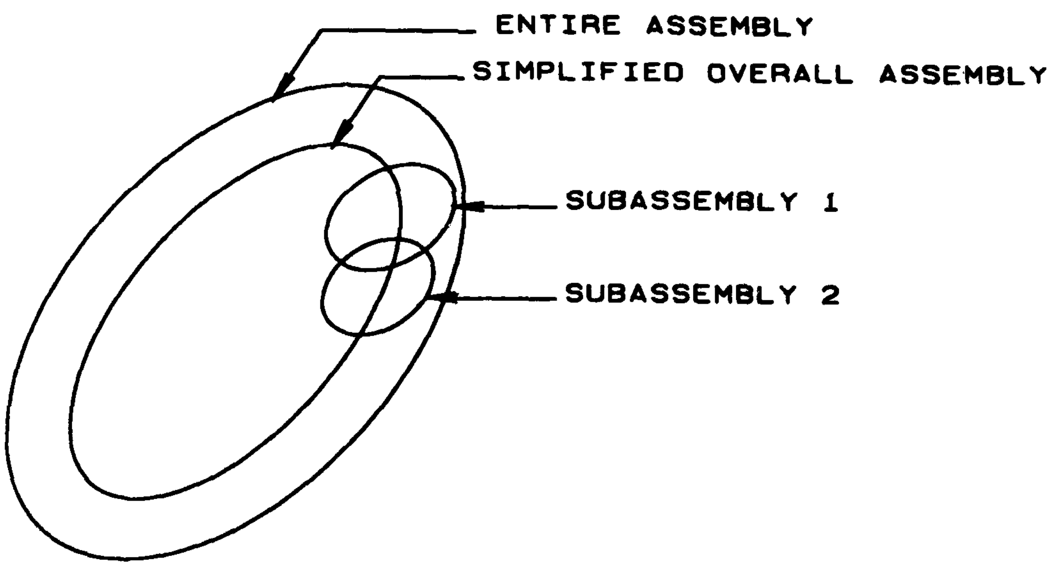


Figure 5. Model for Graphics Simplification.

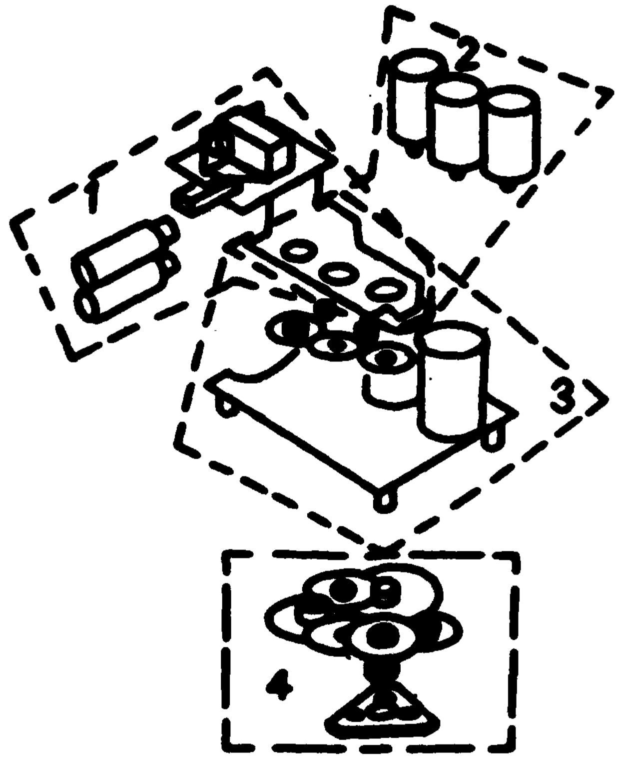


Figure 6. Simplification of Illustrated Parts Breakdown.

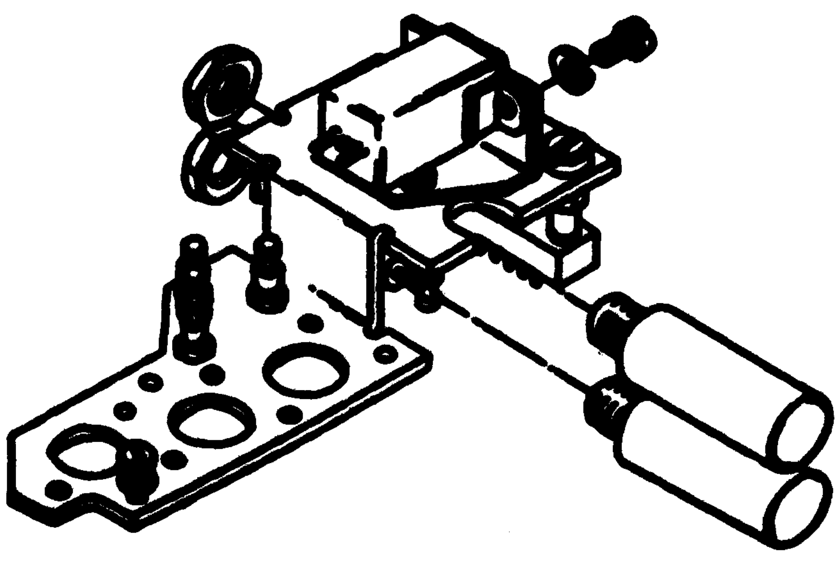


Figure 7. Graphic Detail of Subsection 1.

The presentation of schematics and block diagrams presents similar problems. Typical blocked schematics and wiring diagrams presented in technical orders are too large for direct transliteration and presentation on a cathode-ray tube (CRT) without an unacceptable loss of detail. Thus, it was necessary to develop a simplified means of breaking the diagrams into smaller diagrams which are suitable for presentation on a CRT while providing the technician with a means of maintaining his orientation within the total realm (cognitive field) represented by the schematic. Several potential approaches were considered.

One approach proposed for screen presentation of large, complex drawings was to show a simplified overall diagram illustrating the energy flow relationships with numeric identifiers which allow the technician to call up a more detailed presentation of the subsection of the diagram. Figure 8 presents an example of how the overall diagram could be presented. In this diagram, the components and interconnections are shown without identifying information. Figure 9 presents an example of a frame that would be presented in response to a request to see subsection 5 of the diagram in detail.

Another proposed approach is the use of "matching-to-sample" techniques for comparisons between functional diagrams or blocked schematics and electrical schematics. Figure 10 presents an example of this approach. The functional description for the board is shown in the top of the illustration. It is matched with the blocked schematic shown in the lower section of the illustration. The functional description is ordered and positioned to match the blocked schematic below.

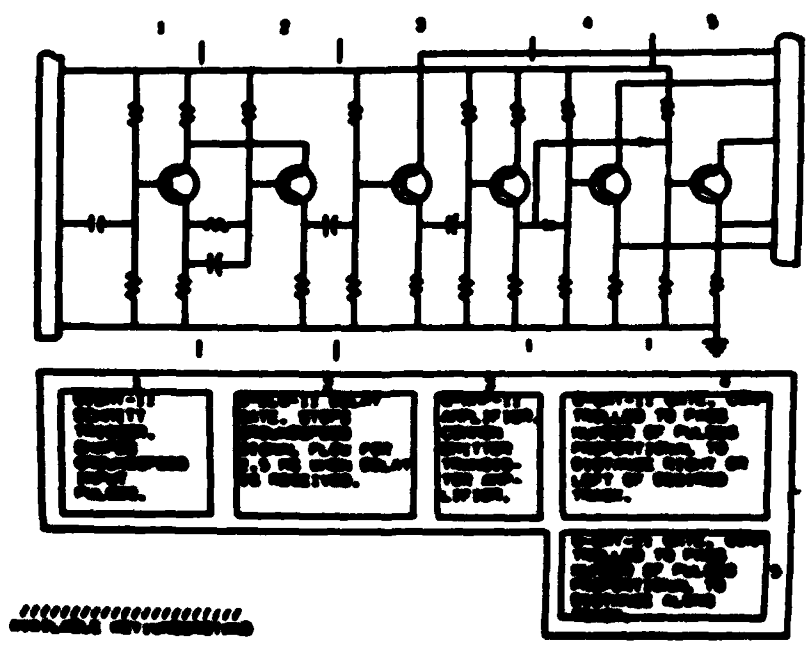


Figure 8. Simplified Overall Wiring Diagram.

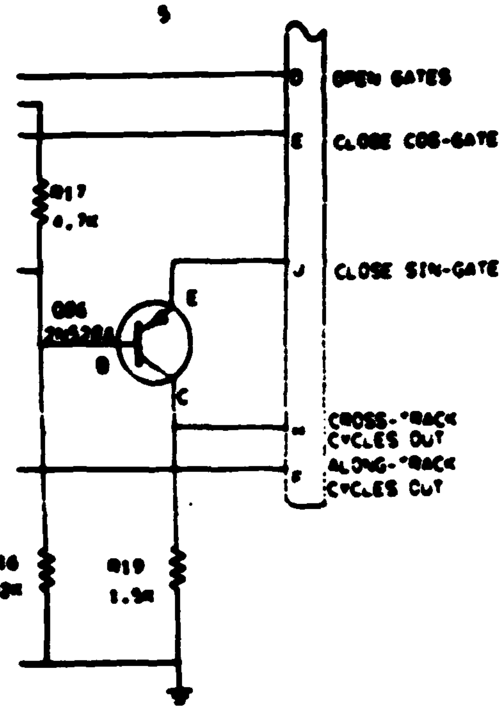


Figure 9. Expanded Detail of Subsection 5 of wiring diagram.

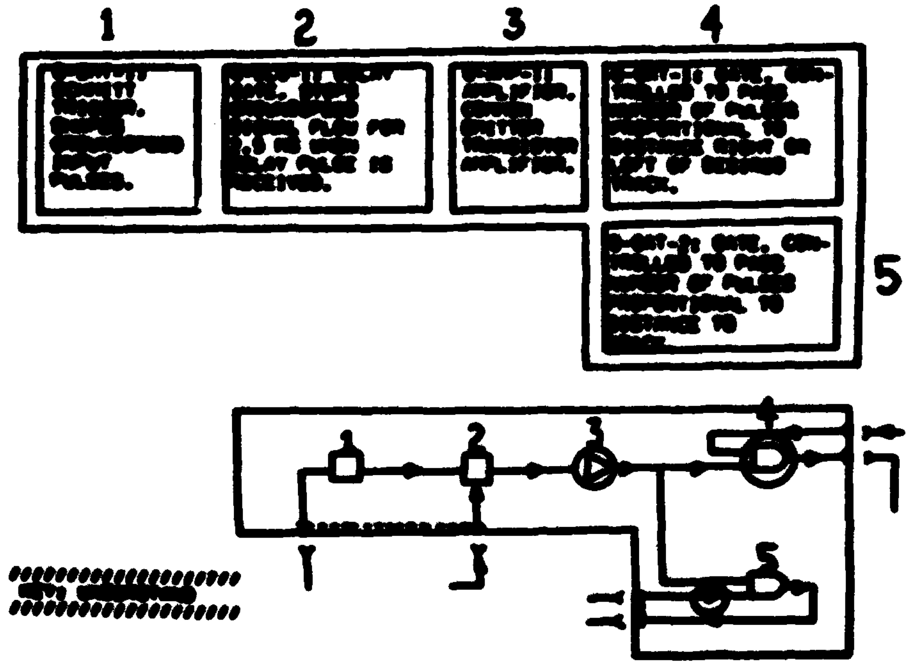


Figure 10. Matching-to-Sample Technique of Graphics Simplification.

Graphics Cuing Techniques. Several graphics cuing techniques are available which enhance the presentation of technical data. Numeric and labeling cues are essential for relating illustrations to textual material and providing a means of retrieving pool data. Numeric cues have two main uses. They can be used following a component name to identify the component on a corresponding illustration. They can also be used to request that the computer provide specified information on a given component shown on an illustration.

Line parameters can also be used as graphics cues. Various line parameters should be adjustable for use as cues. Several degrees of line thickness can be used in an illustration to communicate specific information. For example, an extra-thick line could be used to indicate the major energy flow paths in a blocked schematic. Another line parameter which can be varied is degree of brightness. Level of brightness could be used to indicate foreground/background relationships or to highlight a signal flow of interest on a schematic. Dashed lines could be used to delineate sections of an illustration. For example, dashed lines could be used to separate functional sections of a schematic.

Color, shading, cross-hatching, and blinking are additional cuing techniques with potential for use in automated technical data systems. These cues were not investigated in the studies. However, it was recommended that they be studied to determine if they enhance the discrimination of the technician.

Pseudoanimation. Pseudoanimation refers to a technique for presenting procedural instructions without using textual materials. A series of static drawings (line drawings) are used for illustrating how manual tasks should be performed. This approach is based upon the operant conditioning concept of behavioral chaining in which

> ...the performance of an act is viewed as a serial chain of behavioral operations. Each member leads to the next until the occurrence of the terminal member that leads to reinforcement. The potential applicability of pseudoanimation, therefore, is that of providing discriminative cues that guide imitative responses, the execution of which constitutes a recommended manually performed procedure. (Frazier et al., 1979, p. 46)

Since pseudoanimation provides instructions on how to do a task without the use of verbal descriptions, it can be said to be "culture- or language-free." Pseudoanimation was only partially evaluated in these studies.

The illustrations used in pseudoanimation are digitized drawings showing technicians performing the task. The line drawings are simplified by eliminating unnecessary detail. Two approaches may be used in developing pseudoanimation instructions. The first approach uses one illustration to depict a procedural step. The second approach uses two illustrations on the same frame to depict each step. The first illustration presents the initial condition (e.g., position of hand) and the second illustration presents the condition after the step has been completed. Figure 11 presents an example of the second approach. The illustration on the left presents the initial hand

position. The illustration on the right presents the terminal hand position when the step has been completed.

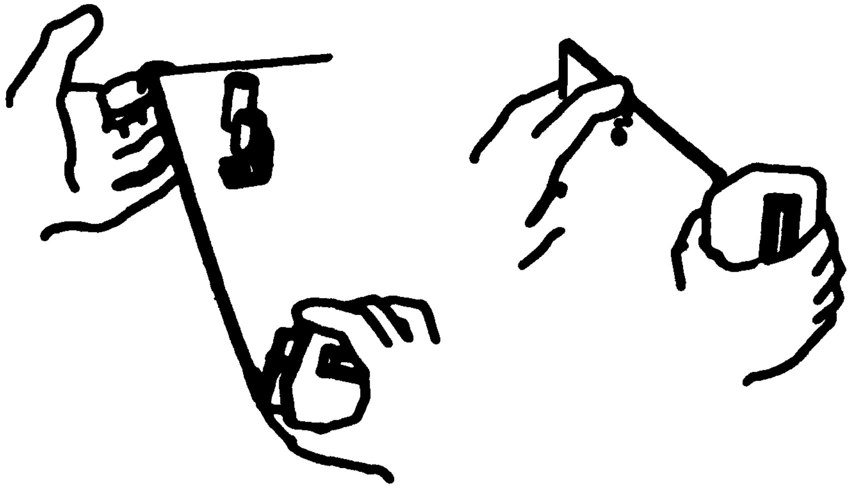


Figure 11. Example of Pseudoanimation Frame Using Two Illustrations.

Pseudoanimation was not fully evaluated in these studies. The authors believed that it had potential for use primarily with personnel with limited language skills or in cases where a given set of data is to be used by personnel of several nationalities and translation into several languages would not be practical. Further study is recommended. Of particular concern is determining the maximum degree of complexity of tasks which can be presented effectively using pseudoanimation.

Phase II. Preliminary Laboratory Demonstrations

After the human factors requirements analysis was completed, the next step was to develop a preliminary laboratory prototype of a computer-based maintenance aids system to test and demonstrate the concepts developed. The system developed was not intended to be representative of a computer-based maintenance aids system but to provide a research tool for testing and refining the concepts developed on a preliminary basis. The preliminary system included the basic elements required for a computer-based maintenance aid: a minicomputer, a graphics terminal, a floppy disk drive, and associated peripherals. The components are briefly described below.

A 16-bit minicomputer with 64K bytes of main memory served as the host unit. It was interfaced to a Hughes CRT graphics terminal. The terminal had a 9 x 12 inch viewing area, with a viewable matrix of 1536 x 2048 pixels. It had a 6-to-1 zoom capability. The terminal had a continuous zoom capability

for positioning and enlarging the display image. The zoom and image positioning were controlled by a joystick. The writing speed was 1,760 inches per second for long and short vectors. The writing speed for characters was 2,000 per second. The system had linear and conic vector-generation capabilities as a standard hardware feature. Also, it was capable of 2-D rotation and translation. The terminal's keyboard was relabeled and redefined via software to provide a means of simulating the function key concept.

External memory was provided by a dual floppy disk system. A digitizing table and controller were used to digitize graphic materials. A high-speed printer and carousel terminal were also available for programming purposes.

Technical data for three tasks were developed for use in a preliminary evaluation and demonstration of the concepts. The three tasks were a remove and replace task, a troubleshooting task, and a training/familiarization task. The remove and replace task was adapted from a Job Guide Manual for the C-141 aircraft. It was used to demonstrate the three-track and pool concepts. Extensive opportunities to switch back and forth between tracks and to call up pool data were provided. It featured simplified graphics, supervisor/technician discourse, and a simulated function keyboard.

The troubleshooting procedure was adapted from a portion of a fully proceduralized troubleshooting aid for a navigational computer (AN/ASN-35). This procedure was used to demonstrate the efficient computer management of the fault-tree troubleshooting approach. It also demonstrated the placement of tolerance data at the point required and the ready access to reference material to minimize search time.

The third procedure was used to demonstrate the potential use of the system as an aid for training and equipment familiarization. The procedure provided instructions for the setup and calibration of the Textronix 535B oscilloscope. The goal was to show: (a) how a newly assigned technician can use the system for rapid familiarization with special or new test equipment, and (b) how an experienced technician can use the system for refresher training on equipment that he has not used recently. The procedure also provided an example of how supplemental procedures could be used as pool data. For example, if a technician were instructed to use the oscilloscope but could not remember how to set it up, he could retrieve the procedure from the pool.

The demonstrations were successful in illustrating the concepts developed in the human factors analysis and proving the overall feasibility of a computer-based maintenance aids system. In addition, they provided the basis for refinement of the overall system and the concepts developed. Specific refinements were incorporated in the system in preparation for a more complete demonstration in the next phase.

Phase III. Preliminary System Evaluation

The objective of this phase was to conduct a more thorough evaluation of the concepts and the prototype system. This was accomplished by developing data in the proper formats for two maintenance tasks and having experienced maintenance technicians use the system to perform simulated maintenance tasks.

Sample Technical Data Development. Technical data were developed for two tasks for use in the evaluation. They were a remove and replace task and a troubleshooting task.

1. Remove and Replace Task. The remove and replace task was the same task (remove and replace engine starter control valve) as that used for the earlier demonstrations. For this evaluation, the data were extended and put into a fully proceduralized job performance aid format. The data were presented in three levels of detail or tracks. The data are described in the following paragraphs.

Track 3 data were designed for the inexperienced technician or for experienced technicians with limited knowledge of the task. This track was fully proceduralized with relatively fine step sizes. The procedures were keyed to locator illustrations to facilitate location of referenced components. Extensive pool information was made available. Figure 3 is an example of a frame presented at the Track 3 level.

Track 2 data were designed for technicians who are familiar with the task but have not mastered it. This track provided procedural information using relatively coarse procedural steps (turn off power--without explanation of how). Locator illustrations were not usually available unless the technician requested them. Pool data were available for reference when needed. Figure 2 is an example of a frame presented at the Track 2 level.

Track 1 data were designed for 7-skill-level and some 5-skill-level technicians with relatively extensive experience on the task. This track was even less detailed. It consisted primarily of general and special repair notes, quantitative information (tolerances, capacities, etc.), and warnings and cautions. Notes were expressed in proceduralized fashion. The list formats key was available in case the technician found that he needed more information. Figure 1 is an example of a frame presented at the Track 1 level.

After the remove and replace task was completed, the display shown to the technician moved directly to a checkout procedure and then to the proper data for any required follow-on tasks. All text was written in a conversational mode. An available-keys box was provided at the bottom of each frame. This was used to list the function keys that were active at that time. Pressing any other key resulted in an error message.

2. Troubleshooting Task. Two types of troubleshooting aids were developed: a fully proceduralized troubleshooting aid and a deductive troubleshooting aid. The fully proceduralized troubleshooting aid was designed to troubleshoot the AN/ASN-35 navigational computer to identify a faulty circuit card and to isolate a fault on that card (Schmitt Trigger Board). The deductive aids were designed to troubleshoot the card to identify a faulty component on the card. The fully proceduralized troubleshooting aids were similar in format and level of detail to those used for the remove and replace task and are not further described here.

The deductive troubleshooting aid made four types of reference data available to the technician and allowed him to create his own troubleshooting strategy. The technician was given a choice of: (a) blocked schematic

diagrams; (b) a functional description; (c) electrical schematic; and (d) parts locator diagram. The technician was able to select any of the above options and to switch back and forth between them as he wished. In addition, a variety of pool information, such as theory of operation or proceduralized instructions on how to make various checks, was available.

3. Illustrated Parts Breakdown (IPB). A limited sample of IPB data were developed for evaluation. The data used the simplified overall assembly approach described above under Phase I.

Evaluation Procedure. Sixteen experienced Air Force Reserve technicians served as subjects for the evaluation. Each technician completed both tests under simulated conditions.

For the remove and replace task, there was no equipment available to allow the technicians to actually perform the task "hands-on." Therefore, the technicians simply viewed the data on the display and interacted with the system. After completing each task, the technicians were asked to complete a questionnaire regarding format, display options, and other features of the system.

For the troubleshooting task, each technician used the fully proceduralized troubleshooting aid to troubleshoot the computer to identify the faulty card. At that point, he was given the choice of troubleshooting the card using the fully proceduralized aid or using the deductive aid. The AN/ASN-35 navigational computer was available for the test. However, the necessary test equipment was not available for troubleshooting the system to the card level. To realistically simulate troubleshooting the computer, each technician went through the procedure using the computer (flipping switches, locating test points, etc.). When a test was called for, the experimenter provided the technician with the results of that test. Since troubleshooting the Schmitt Trigger Board required only a voltmeter and oscilloscope, it was possible for the technicians to actually perform this task. Each technician completed a questionnaire after completing the troubleshooting task.

The IPB data were evaluated by having the technicians manipulate the data base and then having them complete a questionnaire to give their reaction.

Results. The results of the questionnaires are presented in Tables 2 and 3. In addition to the scaled questions reported in the tables, technicians were asked to give verbal comments on what they liked and disliked and to give suggestions for improving the system. Representative observations drawn from their comments are summarized below:

1. The technicians' comments on the system were generally positive. Positive feelings were expressed in comments such as "it is a powerful training tool," "good guide to completing routine tasks," "flexible in allowing the technician to work at his own level," "impressive," "anyone off the street would be able to do it," and "liked the detail level of the instructions."

2. The tracks and pools were described as the most useful features of the system.

3. The graphics were considered to be the least useful feature. They were described by several technicians as "ambiguous," "sloppy," and "unclear."

4. The system should be made capable of presenting schematic information simultaneously with component layout information.

5. The schematics should be labeled to facilitate comparison with component layout diagrams.

Table 2. Summary of Questionnaire Results on FPJPA Format Design[a]

Issue	Finding	Number of participants
1. Overall Effectiveness	Excellent	7
	Good	8
	Fair	1
2. Affective Reactions		
a. Working with System	Very enjoyable	7
	Pleasant	7
	Neutral	2
b. Language Used	Informal and relaxed	7
	Formal and rigid	1
	Between	8
c. Dialog	Enjoyable and efficient	6
	Efficient	7
	Enjoyable	3
3. Completeness	Complete enough	15
	Not complete enough	1
4. Comprehension	Easy to understand	12
	Fairly easy to understand	4
5. Dialog Usability	Collection of facts	10
	Complete facts	3
	Like a person	3
6. Ability to Work at One's Level	Easily possible	14
	Possible with effort	1
	Impossible	1
7. Function Key Completeness	Covered everything needed	12
	Additional suggestions	2

[a]Adapted from Frazier et al., 1979, p. 54.

6. Having to switch back and forth between diagrams and pool information was consistently reported as the least useful feature of the deductive troubleshooting aid. Simultaneous display of several types of information was suggested as the solution to this problem.

7. Inability to present full labeling of complex system schematics was seen as reducing the usability of schematic information.

8. The use of system guidance which provided the technicians with the benefits of the knowledge of experienced technicians was seen as the most useful feature of the fully proceduralized troubleshooting aids.

Table 3. Summary of Questionnaire Results on Deductive Aids[a]

Issue	Finding	Number of participants
1. Overall Effectiveness	Excellent	8
	Good	9
2. Affective Reactions		
a. Working with System	Very Enjoyable	5
	Pleasant	7
	Neither	4
b. Language Used	Informal and Relaxed	5
	Formal and Rigid	1
	Between	10
c. Dialog	Enjoyable and Efficient	6
	Enjoyable	3
	Efficient	4
3. Completeness	Complete Enough	16
4. Comprehension	Easy to Understand	11
	Fairly Easy to Understand	4
5. Dialog Usability	Collection of Facts	11
	Complete Facts	2
6. Ability to Work at One's Level	Easily Possible	11
	Possible with Effort	2
	Impossible	2
7. Function Key Completeness	Covered Everything	13
	Additional Suggestions	2

[a]Adapted from Frazier et al., 1979, p. 56.

9. The presentation of textual information on the same screen as the graphic aids was seen as the most useful feature of the deductive troubleshooting aids.

10. Technicians responded favorably to the provision of estimates of fault probabilities based on other technicians' experience in troubleshooting the same system.

11. The printed circuit layout diagrams were seen as the most useful of the deductive aids provided. Theory of operation and other information supporting improved "in-the-head" knowledge were seen as useful but secondary.

12. The technicians' evaluations of the IPB data were uniformly positive. The zoom capability was often cited as a strong positive factor.

13. It was suggested that a reduced-size overall view of the assembly be provided in the corner when a detailed illustration of a section of the assembly is presented.

Phase IV. Synthesis of Results

In this final phase of the effort, the findings were compiled and the fundamental requirements for a computer-based maintenance aids system were developed. The fundamental system requirements were based on criteria developed in the studies. The criteria were developed "solely with the needs of the maintenance technician in mind" (Frazier et al., 1979, p. 65). The authors emphasized that "...any candidate system intending to disseminate information to maintenance technicians must be able to meet these requirements if the system is to be considered usable" (Frazier, op. cit.). The basic requirements for a computer-based maintenance aids system are described below.

Basic System Design Requirements. The system must meet the following requirements.

1. Be truly interactive and communicate with the technician in natural and acceptable ways.

2. Use a function key panel that will allow the technician to retrieve information in an easy and convenient manner.

3. Support the use of improved job performance aids, including proceduralized, nonproceduralized, deductive, and directive aids.

4. Use multiple levels of detail (tracks) to provide information tailored to the experience and skill level of the user.

5. Use information "pools" to provide reference information and "fill in gaps" in the individual's knowledge.

6. Use simplified graphic techniques which eliminate unnecessary detail.

7. Be fully portable, ruggedized, and suitable for use in a variety of environmental conditions.

8. Provide reference data when and where needed.

9. Provide for quick retrieval and display of data.

10. Collect performance data for training, evaluation, supervisory, and logistics management purposes.

Hardware Requirements. The major hardware requirements are summarized below.

1. Portability. A system for use on the flightline must be suitable for transportation by two people. It should be easily disassembled and re-assembled. The weight of any component should not exceed approximately 60 pounds. The system should resist the normal shock, vibration, humidity, and heat that may be expected in the maintenance work environment. The keyboard should be able to survive a 4- to 5-foot drop onto a hard surface. It is anticipated that the system will be mounted on a cart.

2. Host Computer. The host computer should be a mini- or microcomputer with a minimum of 64K bytes of main memory. This recommendation assumes that a separate graphics processor (graphics terminal) with 32K bytes of core memory will be provided in a graphics terminal. If a graphics processor is not provided, an additional 32K bytes of main memory will be required for the host computer.

3. Graphics Terminal. A separate graphics processor with 32K bytes of main memory is required. The terminal (or the terminal and the host computer) must provide the following capabilities:

a. Scaling and Positioning. The system must have a capability to zoom an image. A 6-to-1 zoom capability is recommended. The system must also have the capability to reposition the image in conjunction with large graphics.

b. Function Generators. Character generators for all standard characters, with adjustable sizes, are required. Conic and linear function generators are required for data compression purposes.

c. Graphics Display. The graphics display should have a resolution of no less than 120 pixels per inch. The viewing area should be at least 108 square inches.

d. Writing Speed. The writing speed should be no less than 2,000 inches per second for graphics.

4. Direct Access Storage. The prototype system should have at least 15 megabytes of direct access storage. This amount assumes that the system is loaded from a larger archival data base.

5. Keyboard. A special function keyboard should be provided. The keyboard should provide: the function keys described earlier, standard alphabetic characters, a numeric keypad, and controls for scaling and positioning the graphic data. The keyboard should have a backlighting capability so that those keys currently active may be lit.

6. Power. The system should operate on 400-cycle, 110-volt power and should incorporate switcher-type power supplies.

Software Requirements. The major software requirements are summarized below.

1. Computer Language. The system should provide a Fortran compiler. This requirement is based on the fact that most commercially available software packages for graphics are written in Fortran.

2. Graphics Software. A graphics software library should be provided with capabilities for:

a. Positioning the cursor;

b. Drawing figures such as curves, arcs, circles, ellipses, etc.;

c. Rotating a portion of a graphic around a specific point;

d. Setting an object scale factor;

e. Setting gray scale levels for various portions of a graphic; and

f. Drawing dashed lines of various patterns.

3. Text Editor. A text editor with the following capabilities is needed:

a. Utility text editing;

b. Establishing backward and multiple forward pointers;

c. Establishing reference pointers to a graphic file; and

d. Compressing and converting data into a byte string.

4. Applications Program. Applications software for presenting technical data is needed with the following capabilities:

a. Checking whether a technician has access rights to the material requested and denying access if not authorized.

b. Presenting information requested by the technician.

c. Collecting relevant data for performance analysis and maintenance data collection requirements.

Discussion and Conclusions

The feasibility of developing an automated technical data system was demonstrated. The success of such a system is dependent upon whether it fully meets the information needs of the technicians who will use the system. A sound human factors impact analysis is essential for building such a system to ensure its usability and acceptability.

The major needs of the maintenance technician must be considered when developing an automated technical data presentation system. If a sound human

factors impact analysis is not done before building such a system, the resultant system will have limited usability and acceptability.

The availability of suitable hardware and software is a prerequisite of developing such a system. Knowledge of current hardware (as of 1979) and anticipated developments in hardware indicate that the development and deployment of an automated job performance aiding system in the near future is feasible. In the immediate future, portability will be a problem due to the fact that solid-state mass memory devices are not available. Thus, reliance must be placed on magnetic disk random access storage. Similarly, flat-panel technology has not reached the point of providing sufficient graphics resolution. CRTs appear to be the best interim solution.

The study demonstrated that the software support required for an automated job performance aiding system can be developed at this time (1979). However, new software development will be required to streamline the data preparation and retrieval processes. Specific areas requiring software development include applications software for development of graphic materials and software to control the retrieval and presentation of data to the technician.

Technician-oriented considerations are the most important. Many features of the best hard-copy job performance aids are good starting points for developing principles for automated technical data design. Issues such as graphics simplification, having all of the information to do the job at hand, and alternate levels of technical detail have their basis in paper-based job performance aids and are readily adaptable to automated aids.

All of the automated technical data presentation concepts developed and tested in these studies seem worthy of further investigation. Specifically, multiple levels of detail (tracks), the function keyboard, graphics simplification, and pools of auxiliary information seem to have the most promise as design concepts.

Some issues not investigated were considered important to the success of an automated system. The amount and nature of the interchange between the system operator and the system required additional study (and still do). Several design issues in this area required study, including the desirability of having the computer acknowledge each request and the desirability of requiring the technician to indicate that he understands the instruction. Similarly, study was (and is) needed to determine the impact of format considerations and to determine which formats and cuing techniques were the most effective.

III. INITIAL PROTOTYPE DEVELOPMENT EFFORT

In September 1978, a contract was awarded to Unified Industries, Inc. (UII) for the development of a full-scale prototype CMAS for intermediate level (shop) maintenance. Contractual arrangements included a subcontract to BioTechnology, Inc. for development of the MMI, formats, and the human factors aspects of the system design. This work was based on the feasibility studies, and extended and refined the basic concepts developed in those studies.

Work continued on the development of the prototype until March 1981, when it was terminated at the convenience of the Government. Contract termination became necessary when a change in requirements for the system was received from the project sponsor, the Air Force Logistics Command. The change added the requirement that the system must be suitable for deployment in support of worldwide wartime operations. The system under development was designed for use at fixed site locations and was not suitable for deployment. It was determined that it would not be cost effective to modify the system to make it deployable. Thus, the contract was terminated.

During the period of the contract, work was accomplished on several tasks in preparation for the design and development of the system. The work accomplished during this period provided an essential background for follow-on efforts to build a prototype CMAS. The basic hardware (computer system and display) for the prototype system was procured. However, no software was developed. The major areas of work accomplished included:

1. Identification of technicians' information requirements;

2. Development of the MMI;

3. Development of data presentation formats;

4. Development of task analysis procedures appropriate for the development of technical data for automated presentation;

5. Identification of software requirements; and

6. Identification of hardware requirements.

Information Requirements Analysis

A detailed analysis was made to identify the types of information that must be provided by an automated technical data system. This analysis built upon the user analysis developed by Frazier et al. (1979), upon the earlier job performance aids research, and upon the information requirements established by existing technical data specifications. The latter source was examined to ensure that the CMAS is capable of providing all types of data required to maintain a system. In addition, an analysis was made of existing techniques for presenting technical information via automated systems and for presenting improved technical data on paper. The latter emphasized the work of AFHRL and other research agencies to develop improved job performance aids. Work that addressed ways of matching technical data to the skills and needs of the user was examined also.

Man/Machine Interface

The majority of the work accomplished was in the areas of the MMI and the development of technical data presentation formats. Since the contract was terminated before the prototype could be built, only the MMI and technical data format designs were completed. The major characteristics and features of

the MMI design and presentation format designs are presented in the following paragraphs. The materials presented are extracted from Hatterick (1985) and Thomas (1982).

The primary objectives of the MMI design were to provide a system that:

1. Is easy to use and requires no special skills to operate;

2. Provides rapid access to the desired data;

3. Provides for easy movement within the data base;

4. Enhances the performance of the maintenance technician; and

5. Receives positive user acceptance.

To meet these objectives, the MMI provides for multiple levels of detail (tracks), pools of support information, menu access to data, direct access to data, and manipulation of graphics. A special function panel is provided for input of requests to the computer.

Function Panel

The principal component of the MMI design is the special function panel/keyboard which is similar to that proposed by Frazier et al. The panel (Figure 12) is designed to make it easy for the user to find the information that he desires and to move freely within the data base. The panel is designed to make it possible for technicians to accomplish the following operations with one or two keystrokes:

1. Display the next frame in sequence (FORWARD key);

2. Return to the previous frame (REVERSE key);

3. Display a list of available optional information (LIST OPTIONS key);

4. Return (to a procedural frame) from a pool item (RETURN key);

5. Change scale to make a graphic larger or smaller (LARGER and SMALLER keys). A RESTORE key returns the graphic to its original scale;

6. Scroll or pan a graphic to view a different portion of the graphic for graphics larger than the display window (arrow keys);

7. Store a frame of data for immediate recall (HOLD key to store, SHOW key to display);

8. Select data access mode (USER REQUEST key). This function allows the user to change data access modes from the default mode (menu access) to the user request mode and vice versa.

9. Enter YES or NO response (Y = yes, N = no);

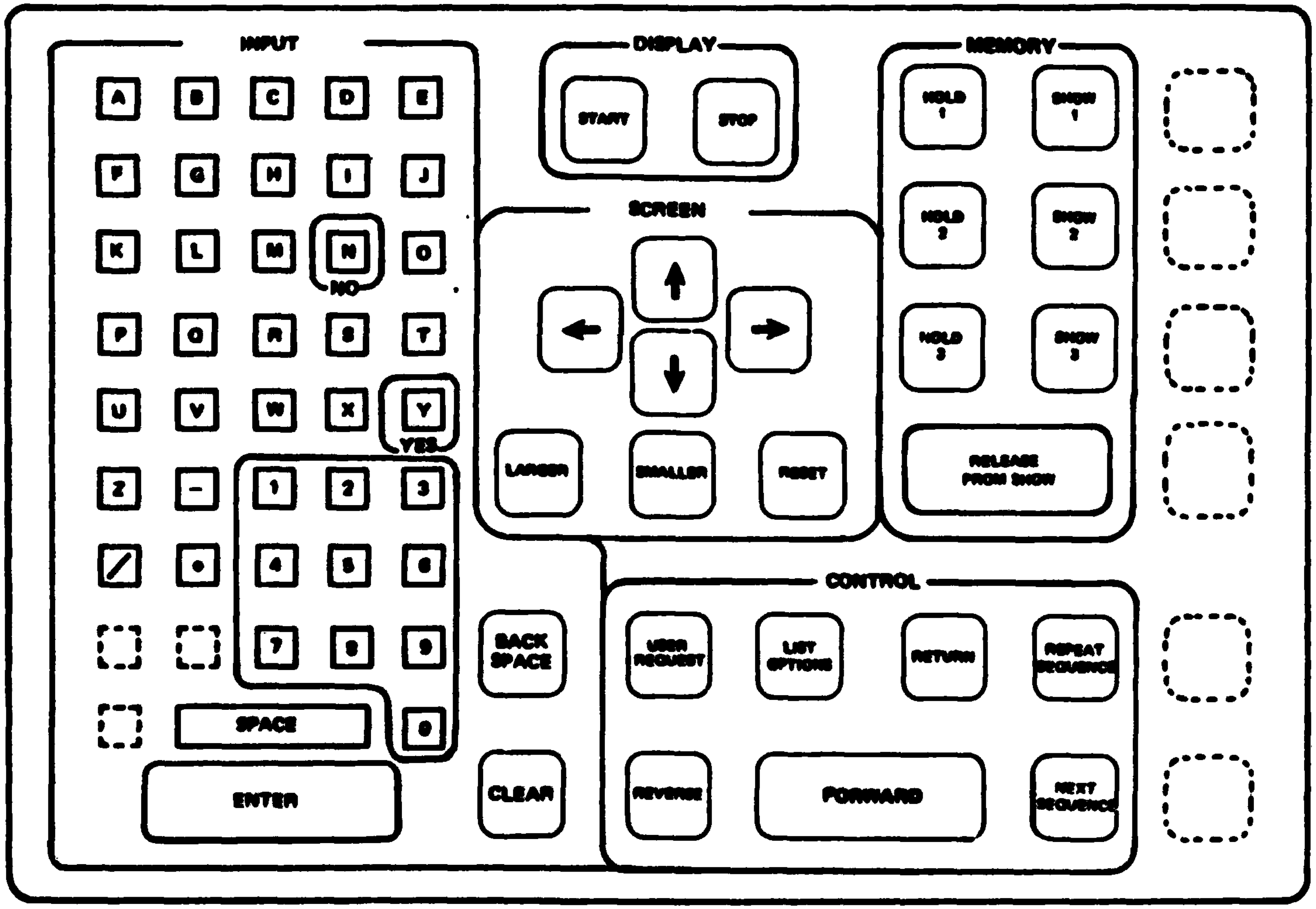


Figure 12. Function Panel Layout.

10. Enter alphanumeric characters for direct access, entry of user identification number, etc.;

11. Turn the system on or off (START key or STOP key);

12. Jump forward to the next major node in the preestablished sequence (NEXT SEQUENCE key); and

13. Jump backward to the next major node in the predetermined sequence (REPEAT SEQUENCE key).

The initial mechanical design for the panel provides for construction as a sealed, liquid proof unit. Membrane keys covered with plastic are used for the keyboard. Function keys on the panel are identified by printing key identifications on an overlay. This approach provides maximum flexibility in that the function key layout of the panel can be changed by simply changing the overlay and modifying the software. The design provides for connecting the panel to the computer system by a cable long enough to allow the user to move the panel to any location in his work area within viewing distance of the display. The contract was terminated before the panel could be constructed.

Data Access Methods

The MMI design provides for four methods of accessing maintenance data: from a standard mode (menu-based access), by a direct access mode, from internal branching within the technical data itself, and from a list of options accessed from within the technical data itself. Illustrated parts breakdown (IPB) information presents some unique data access problems since the data must be accessed using a wide variety of locator information (part number, reference designator, etc.) and must be used for special purposes (e.g., supply). The design provides for the use of a combination of the above approaches to access IPB information. The methods provided by the MMI design for accessing each type of data are briefly described below.

Standard Access. The standard access mode provides access to technical data from a series of menus or tables of contents which progressively narrow the choices until the desired item is located. The successive menus provide for the selection of the appropriate TO (if the data base includes more than one TO), identification of series (A-Model, B-Model, etc.) of the equipment to be worked on, selection of the system, selection of the subsystem, selection of the component, and selection of the specific procedure or other information to be retrieved. Selections from a menu are made by entering the identifying number of the item and pressing the ENTER key. The number of menus required to identify a specific item of information primarily depends upon the size and complexity of the TO and the level within the system of the item of interest (e.g., fewer menus are required to locate a system checkout procedure than to locate the procedure to remove a lower-level component of the system).

User Request Method. The user request method provides the technician with a means of going directly (direct access) to a specific procedure or data element without going through the cumbersome menu selection process. After system sign-on or at any point in any procedure, the technician can activate

the direct access mode by pressing the USER REQUEST function key on the panel. The system then prompts the user to enter the specific request. Using the alphanumeric keys, the technician can retrieve a specific frame or item of information provided that he knows one of the following pieces of information:

Frame Number
Task Number
Fault Code
Maintenance Information Data Access System (MIDAS) Code
Part Number
Reference Designator

Options Menu Access. At any point in a procedure, the user can press the LIST OPTIONS function key. The system responds with a list of options available at that point. The options list may include one or more of the following types of options:

- Change Tracks (more/less detail)
- Pool Information
  - How to use required test equipment
  - Functional diagrams
  - Schematics
  - Theory of operation
  - System descriptions
  - Record of applicable Time Compliance Technical Orders (TCTOs)
  - Parts information
  - User record (sequence of steps followed by user)
  - Lists of tolerances and test specifications
  - Glossaries
  - Test equipment and tool use descriptions/information
- Return to Table of Contents
- List of effective frames (equivalent to list of effective pages in TO)
- Help (how to use the system)
- Quit procedure

Internal Branching. The system design provides the capability to go directly from one procedure to another in certain cases. This capability is provided in the following cases:

1. Another task must be performed prior to the current task (e.g., aircraft must be made safe for maintenance).

2. A follow-on task must be completed to return the system to operational condition.

3. A fault identified in troubleshooting must be remedied before the system can become operational.

When the above situations occur, the system displays a prompt asking the technician whether he wants the procedure required for the new task.

IPB Information Access. The design provides both standard and direct access methods for accessing IPB information. The strategies for locating IPB information are presented diagrammatically in Figure 13.

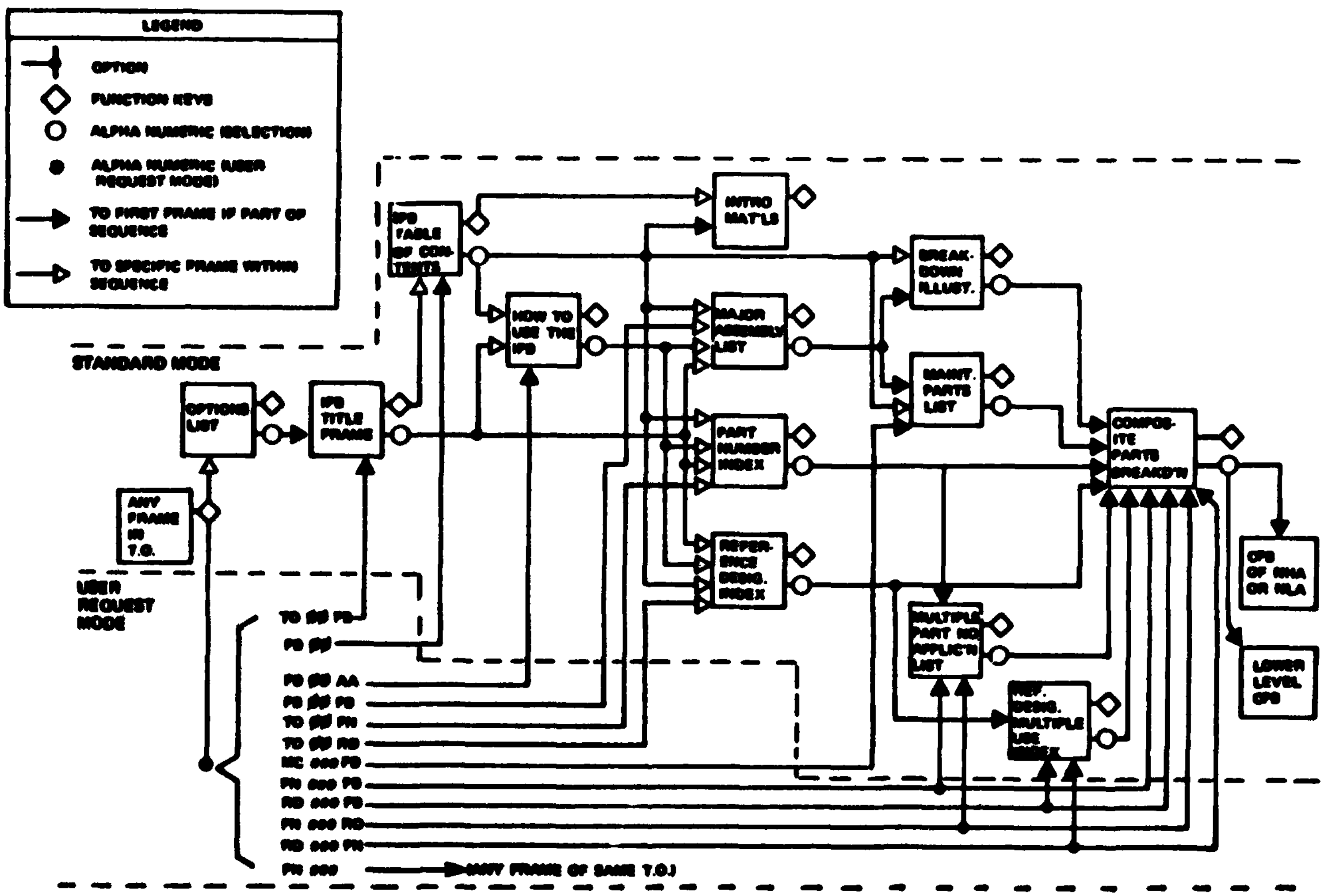


Figure 13. Data Access Pathways for IPB Information.

In using the standard access method, the user is led through a series of menus which help him take the information that he has about the part of interest to narrow the choices until he locates the desired information. The primary menus used are:

Part Number Index
Major Assembly List
Reference Designator Index

One or more submenus may used to further narrow the choices until a frame with the desired information is located.

In the user request mode, the user may go directly to a composite parts breakdown frame which provides specific information on the part or subassembly of interest. This design feature makes it possible for the knowledgeable user to eliminate many intermediate steps.

In addition to the standard access and the user request modes, parts information often can be obtained directly from the options list (provided it is a listed option at that specific point in the procedure).

Multiple Track Definitions

The multiple levels of detail (multiple track) concept proposed by Frazier et al. (1979) was adopted for the prototype system. Technical data were to be provided in three levels of detail or tracks. The three tracks and the intended users are described in the following paragraphs:

Track 3. This track is intended for the novice technician. The novice is described as having a general understanding of the system or similar systems, but having only limited specific knowledge of the system. It is assumed that he is not familiar with specific system components or their location and, therefore, requires assistance in locating them. Also, he is unfamiliar with the procedures required to perform specific tasks. Thus, specific step-by-step instructions are required for him to perform them. It is assumed that the novice has a basic understanding of the use of any required special tools and test equipment, but is not fully proficient in using them. It is anticipated that this track will be used primarily by 3-skill-level technicians. However, it may be appropriate for some 5-skill-level and 7-skill-level technicians who are completely unfamiliar with the specific system or the assigned task.

Track 2. This track is designed for the journeyman technician. The journeyman is described as a fully qualified 5-skill-level technician with at least 6 months of experience on the system. The journeyman is thoroughly familiar with the system and has accomplished most commonly performed tasks on the system at least a few times. He knows the layout of the equipment, can identify its components without aid, and is able to perform routine trouble-shooting tasks on the system with the aid of predeveloped troubleshooting strategies. It is assumed that the technician is proficient in the use of any special tools or test equipment. It is anticipated that this track will be used primarily by fully qualified 5-skill-level technicians. However, it may

be appropriate for 7-skill-level technicians who have not worked on the system for some time, who are transferring from another weapon system, or who are working on a specific task that they have not performed for some time. Also, Track 2 data may be appropriate for some 3-skill-level technicians who have performed the specific task many times.

Track 1. This track is designed for use by the "expert." The expert is described as a technician with extensive experience on the system being maintained, and extensive knowledge of the system and how it operates. He is able to perform most tasks with only limited technical data to remind him of critical actions or needs only specific information such as tolerances. This individual is capable of developing his own strategies for troubleshooting the system using aids such as schematics. It is assumed that the individual is proficient in the use of any required tools or test equipment. Normally, it is anticipated that this track will be used by 7-skill-level and senior 5-skill-level technicians. However, there may be instances in which junior 5-skill-level and some 3-skill-level technicians may be experts on one or more specific tasks (which they have performed many times). In these instances, it may be appropriate for them to use Track 1 data (with their supervisor's approval).

It should be noted that implicit in the above definitions is the philosophy that the track level used should not be based upon the "official" skill level (3-, 5-, or 7-skill-level) but on the technician's knowledge of the specific task to be performed. Thus, simply because a technician is a 7-skill-level, it does not follow that he should always use Track 1 data, or that a 5-skill-level technician should always use Track 2 data. It is possible for a 5-skill-level to be an expert on a given task. In that case, it would be appropriate for him to use Track 1 data. Similarly, it would be possible for a 7-skill-level technician to be completely unfamiliar with a given task. In this case, the use of Track 2 or even Track 3 data would be appropriate.

Format Development

Baseline requirements for the presentation of technical data were based upon materials from MIL-M-38800A, MIL-M-83495, Lobel and Mulligan (1980), Mulligan (1980), and Mulligan and Bird (1980). Formats were developed for each specific type of information identified for inclusion in the CMAS. The formats can be generally classified into three categories: formats for maintenance procedures, formats for troubleshooting procedures, and formats for support information. Formats were developed for presenting maintenance procedures and troubleshooting procedures in three tracks appropriate to the definitions specified above. Formats for nonprocedural support materials are provided in one level of detail. The formats developed are described briefly below. Detailed descriptions of the formats are presented in Hatterick (1985).

Formats for Maintenance Procedures

Maintenance procedures were defined to include all procedural information that does not include troubleshooting, checkout, fault isolation, and test. Formats were developed which were appropriate for the presentation of tasks for the following activities:

Inspection
Cleaning
Disassembly or removal
Assembly or installation
Lubrication
Alignment, adjustment, and calibration
Preoperational check
Repair

The formats for each track have the following characteristics:

Track 3. Track 3 procedures provide the most detail. Each procedure contains the following types of information:

1. Input Conditions. The input conditions provide the information required to prepare to perform the task. The following categories of information are provided:

Applicable serial numbers
Personnel required (number and specialty)
Supplies
Special tools and test equipment
Equipment conditions (including instructions for establishing conditions and requirement to verify condition prior to accessing next frame)
Summary of procedures

(See Figures 14, 15, and 16.)

```
# TO 1C-141A-2-AA                 73-1Ø-ØØ          6JG Ø3592C
# C-141A ENGINE FUEL SYSTEM MAINTENANCE
# TASK 4-3: FUEL PUMP FILTER ELEMENT REMOVAL & INSTALLATION. 1

# INPUT CONDITIONS:                            REMOVE  INSTALL

  • APPLICABLE SERIAL NUMBERS....ALL

# • PERSONNEL REQUIRED......................     1        2
#   - SPECIALIST WILL BE REQUIRED TO MOTOR
#   AFFECTED ENGINE UPON REQUEST DURING FUEL
#   SYSTEM ACTIVATION & CHECKOUT.

  • SUPPLIES:
#   - ONE GALLON PLASTIC CONTAINER...........    1        -
#   - PETROLATUM GREASE, VV-P-236............    -        ✓
#   - O-RING PACKING, MS9Ø21-135.............    -        ✓
#   - WIPING CLOTH OR TOWELS (WIPES).........    ✓        ✓

  • SPECIAL TOOLS AND TEST EQUIPMENT:
#   - MAINTENANCE STAND, TYPE B-4A (ALT:B-1A)    1        1
#   - TORQUE WRENCH, 5ØØ INCH-POUNDS(CALIBRATED)-         1



  ⇨ INPUT CONDITIONS CONTINUED: [FORWARD].
```

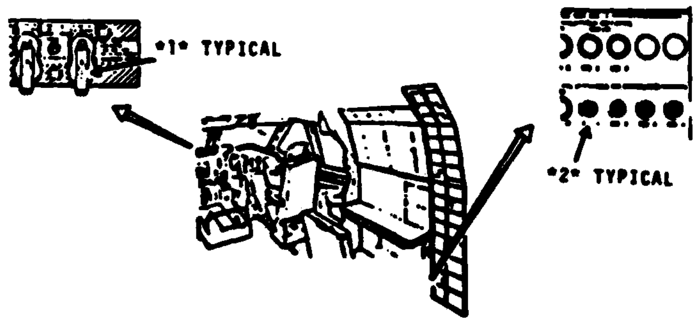
Figure 14. Example of Maintenance Task Input Conditions Frame (All Tracks).

TO 1C-141A-2-AA 73-10-00 5J6 03598D
4-3: INPUT CONDITIONS, CONTINUED. 3

● EQUIPMENT CONDITIONS:

++++++++++++++++++++++++ WARNING ++++++++++++++++++++++++
THE FOLLOWING EQUIPMENT CONDITIONS MUST BE MET BEFORE
DOING THE TASK YOU HAVE SELECTED.
++

- HAS FUEL FROM TANKS BEEN SHUT OFF FOR APPLICABLE ENGINE
  AS SHOWN BY:
  - FIRE EMERGENCY HANDLE *1* PULLED AND TAGGED?
- ENGINE FIRE EXTINGUISHER CIRCUIT BREAKER *2* OPEN AND
TAGGED?



ARE BOTH CONDITIONS VERIFIED? INPUT [YES] OR [NO] [ ];
[ENTER].

Figure 15. Example of Maintenance Task Input Conditions Continuation Frame (Tracks 2 and 3).

TO 1C-141A-2-AA 73-10-00 5J6 03595A
4-3: INPUT CONDITIONS, CONTINUED 4
#

● SUMMARY OF PROCEDURE:
- ENSURE APPLICABLE EQUIPMENT IS IN THE CORRECT CONDITION FOR MAINTENANCE.
- REMOVE FILTER ELEMENT FROM THE FUEL PUMP.
- DISASSEMBLE FUEL PUMP FILTER ELEMENT.
- INSPECT AND CLEAN FUEL PUMP FILTER ELEMENT.
- ASSEMBLE FUEL PUMP FILTER ELEMENT.
- INSTALL FILTER ELEMENT IN THE FUEL PUMP.
- ACTIVATE AND CHECKOUT FUEL SYSTEM.
- PERFORM REQUIRED FOLLOW-ON MAINTENANCE.

● THIS PROCEDURE SHOULD BE PERFORMED USING THE SPECIFIC PROCEDURES WHICH FOLLOW.

FOR NEXT FRAME: [FORWARD].
FOR INSTALLATION PROCEDURES ONLY: [NEXT SEQUENCE].

Figure 16. Example of Maintenance Task Input Conditions Continuation Frame (Tracks 2 and 3).

2. Warning, Cautions, and Notes. This information is imbedded in the procedure immediately prior to the affected steps.

3. Step-by-Step Instructions. Very detailed step-by-step instructions are provided. Each step is keyed to a diagram showing the location of the component referenced. Each frame presents instructions for accomplishing one subtask. The subtask is described, with step-by-step instructions for accomplishing it indentured below. Each component or part referenced in the text is keyed to the illustration. An example of a Track 3 procedural frame is presented in Figure 17.

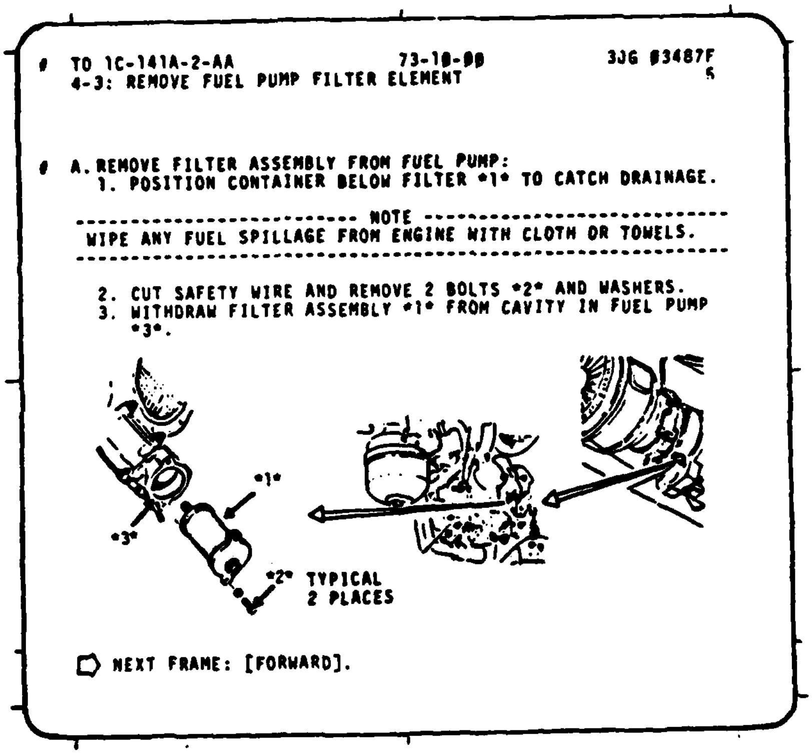


Figure 17. **Example of Maintenance Task Procedure Frame (Track 3).**

Track 2. Track 2 procedures provide the following information:

1. Input Conditions. The input conditions frames for Track 3 and Track 2 are identical in most cases.

2. Warning, Cautions, and Notes. This information is imbedded in the procedure immediately prior to the affected steps.

3. Step-by-Step Instructions. The procedures for Track 2 provide the same basic steps as Track 3, with much of the detail removed. The text description is normally the same as the subtask description provided in Track 3, without the detailed instructions for completing the subtask. Illustrations with keyed callouts may be used to supplement the text depending upon the requirements of the task being performed. An example Track 2 procedure frame is presented in Figure 18.

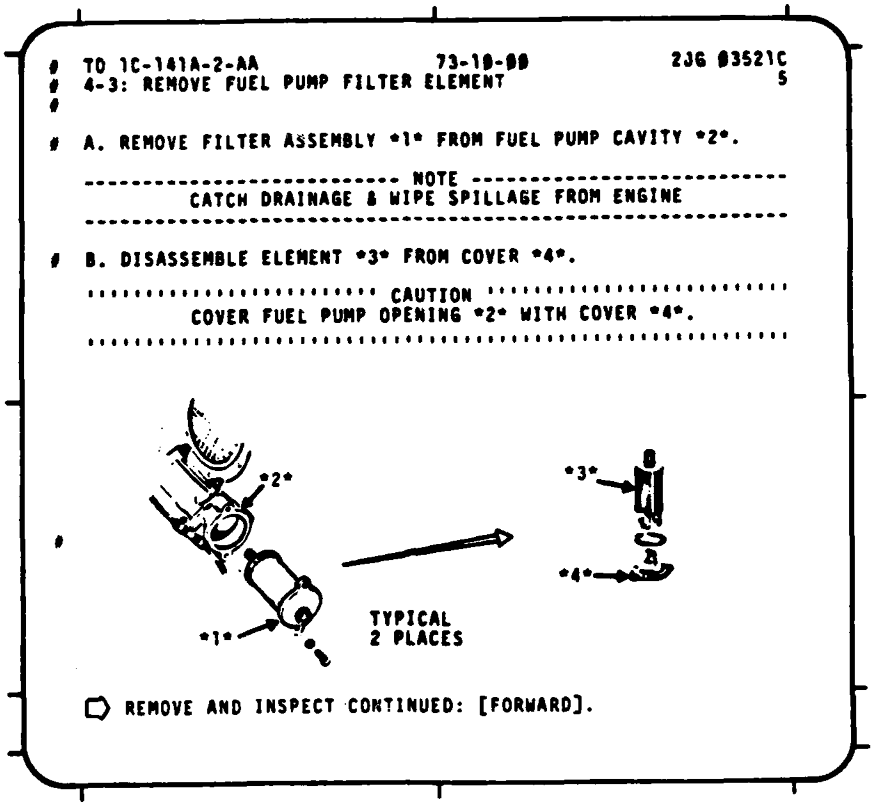


Figure 18. Example of Maintenance Procedure Frame (Track 2).

Track 1. The Track 1 procedures provide the following types of information:

1. Input Conditions. The input conditions for Track 1 are basically the same as used for Track 2 and 3 with the exception that instructions for establishing required equipment conditions may be somewhat less detailed.

2. Warnings, Notes, and Cautions. This information is presented in the Input Conditions with the Summary of Procedures.

3. Procedural Information. Expert maintenance technicians require limited procedural information. In most cases, the Summary of Procedures from the Input Conditions is used to present this information. In some cases, such as complex alignments, additional procedural information may be provided. If the expert technician requires more information, it may be obtained by accessing the Track 2 data. An example of a Track 1 procedural frame is included in Figure 19.

Formats for Troubleshooting Procedures

Troubleshooting procedures are also presented in three levels of detail. The criteria for establishing the levels of detail are the same as for maintenance procedures. Troubleshooting procedures are provided for the test and checkout function and the fault isolation function.

```
# TO 1C-141A-2-AA                    73-10-00              1J6 03596A
# 4-3: INPUT CONDITIONS, CONTINUED                                  4
#

  • SUMMARY OF PROCEDURE:
    - ENSURE APPLICABLE EQUIPMENT IS IN THE CORRECT CONDITION
      FOR MAINTENANCE.
    - REMOVE FILTER ELEMENT FROM THE FUEL PUMP.
    - DISASSEMBLE FUEL PUMP FILTER ELEMENT.
    - INSPECT AND CLEAN FUEL PUMP FILTER ELEMENT.
    - ASSEMBLE FUEL PUMP FILTER ELEMENT.
    - INSTALL FILTER ELEMENT IN THE FUEL PUMP.
    - ACTIVATE AND CHECKOUT FUEL SYSTEM.
    - PERFORM REQUIRED FOLLOW-ON MAINTENANCE.

  ⇨ IF YOU NEED MORE INFORMATION: [LIST OPTIONS].
```

Figure 19. **Example of Maintenance Task Input Conditions Summary Frame (Track 1).**

The troubleshooting formats used for the prototype system are based upon the logic tree troubleshooting aid (LTTA) as defined by Mulligan (1980) and MIL-M-38800A. The LTTA is composed of two basic elements: the checkout procedure and the fault isolation procedure. The fault isolation procedure immediately follows the checkout procedure. The user is "branched" to the appropriate section of the fault isolation procedure when an out-of-tolerance condition is identified during the checkout of the system. The formats for each track have the following characteristics:

Track 3. "Enriched" LTTAs are used to present troubleshooting procedures for the most detailed track. The procedures and logic used for Tracks 2 and 3 are the same. Track 3 provides more detail on how to perform the specified tests and how to set up and use the specified checks and tests. The Track 3 procedures include the following:

1. Input Conditions. Separate input conditions frames are provided for the checkout and fault isolation sections of the LTTA. The input conditions information is similar to that provided for maintenance procedures. However, there are some exceptions. The checkout input conditions include a summary of the procedure. Fault isolation input conditions do not contain this information since the sequence of steps is unpredictable and varies due to the conditional branching applied.

2. Warnings, Cautions, and Notes. The rules for providing warnings, cautions and notes for maintenance procedures apply.

3. Checkout Procedures. The format for presenting checkout procedures is the same as for maintenance procedures (see Figure 20(a)). Dual-level subtask elements are followed by detailed instructions on how to accomplish each subtask. The procedures are completely integrated with illustrations showing the location of referenced components. Each subtask starts on a new frame. Several frames may be required to present the complete subtask. When follow-on frames are used, the subtask is identified on each frame. Questions are phrased so that a YES response indicates a normal condition and a NO response indicates an abnormal condition. An arrow placed at the side of the frame is used as a cue to indicate that an input from the user is required. When the user responds to a question, the system replies with a feedback message (Figures 20(b) and 20(c)). When an out-of-tolerance condition is identified, the feedback message provides the option to go to the appropriate section of the fault isolation procedure.

4. Fault Isolation Procedures. Fault isolation procedures are presented in a dual-level format similar to that used for checkout procedures (see Figure 21). An exception is that the subtasks are enclosed in "boxes." The boxes are used to provide a visual distinction between checkout and fault isolation procedures. The boxes also improve the compatibility between the Track 2 and Track 3 fault isolation procedures. As in the checkout procedures, arrows are used to indicate that a user input is required. Questions are stated so that a YES indicates an in-tolerance condition and a NO response indicates an out-of-tolerance condition. The system responds to inputs in response to a question with a message stating the meaning or implication of the input test results.

Track 2. Track 2 troubleshooting procedures are presented at the middle level of detail as defined in Mulligan (1980). The Track 2 procedures contain the following:

1. Input Conditions. The input conditions frames are the same as Track 3.

2. Warnings, Notes, and Cautions. This information is presented the same as Track 3.

3. Checkout Procedures. The sequence of procedures (logic) is the same as used for Track 3 (see Figure 22). However, it is assumed that the user is sufficiently familiar with the equipment and that he knows where the referenced controls, indicators, and components are located. Thus, illustrations are not provided to show the location of these items. It is also assumed that the user knows how to perform standard tests and checks. Detailed instructions are not provided on performing these actions.

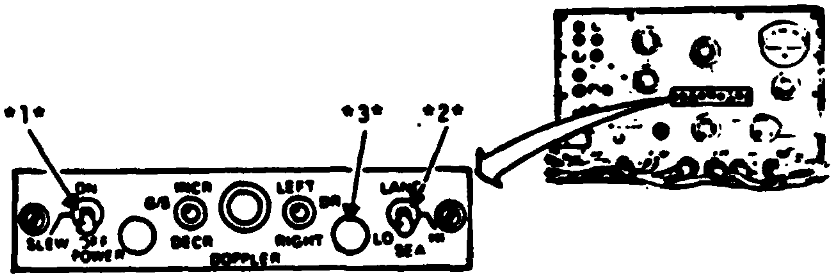
4. Fault Isolation Procedures. Track 2 fault isolation procedures are presented in a format very similar to that used to present LTTAs in a paper medium (see Figure 23). Directions for accomplishing a test are presented in a box with arrows leading to the next test (box) for in-tolerance conditions and an arrow leading to a branching instruction for out-of-tolerance conditions. For branching situations, the user is required to input the appropriate code (a, b, c, etc.) to cause the computer to retrieve the proper

Series 10/8/50

\# TO 10P3-ASQ-99-2-AA 26-22-03 3FI 07254C
\# CHECKOUT 3-1: B. MANUAL GROUND SPEED SLEW CHECK 2

\# 1. CHECK MEMORY LAMP:
\# A. SET POWER SWITCH *1* TO SLEW.
\# B. SET TERRAIN SWITCH *2* TO LAND.
\# DOES MEMORY LAMP *3* LIGHT AND REMAIN LIT?

\#



a. \# INPUT EITHER [YES] OR [NO]: [ ]; [ENTER].

b. INPUT EITHER [YES] OR [NO]: [YES];[ENTER].
MEMORY LAMP IS OKAY. CHECK LEFT SLEW: [FORWARD].

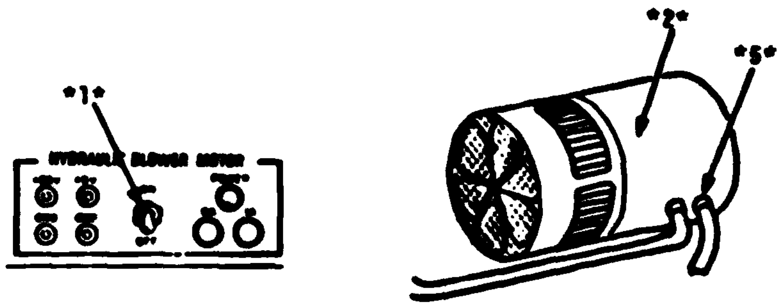
c. INPUT EITHER [YES] OR [NO]: [NO]; [ENTER].
MEMORY CIRCUIT FAULT. FOR LT 3-2: [FORWARD].

Figure 20. Track 3 Troubleshooting - Example of Enriched Checkout Frame.

TO 12PS-CH495-2-AA 29-21-03 3FI 01131C
LT 10-1: HYDRAULIC BLOWER DOES NOT SPIN WHEN TURNED ON. 4

3. CHECK MOTOR TO BLOWER SHAFT:
A. PLACE MECHANIC'S STETHESCOPE ON OUTLET PORT *5* OF MOTOR *2*.
B. SET MOTOR SWITCH *1* TO ON.
C. LISTEN FOR A COMBINATION RUMBLING AND WHINING NOISE OF TURNING MOTOR.

\# IS THE MOTOR QUIET?



a. # INPUT EITHER [YES] OR [NO]: [ ]; [ENTER].

b. INPUT EITHER [YES] OR [NO]: [YES]; [ENTER].
QUIET MOTOR MEANS SPLINE SHAFT IS OKAY: [FORWARD].

c. INPUT EITHER [YES] OR [NO]: [NO]; [ENTER].
NOISY MOTOR MEANS SPLINE SHAFT IS BAD. REPLACE SPLINE SHAFT WITH JG 7-5. FOR PROCEDURE: [FORWARD].

Figure 21. Track 3 Troubleshooting - Example of Enriched Logic Tree Frame.

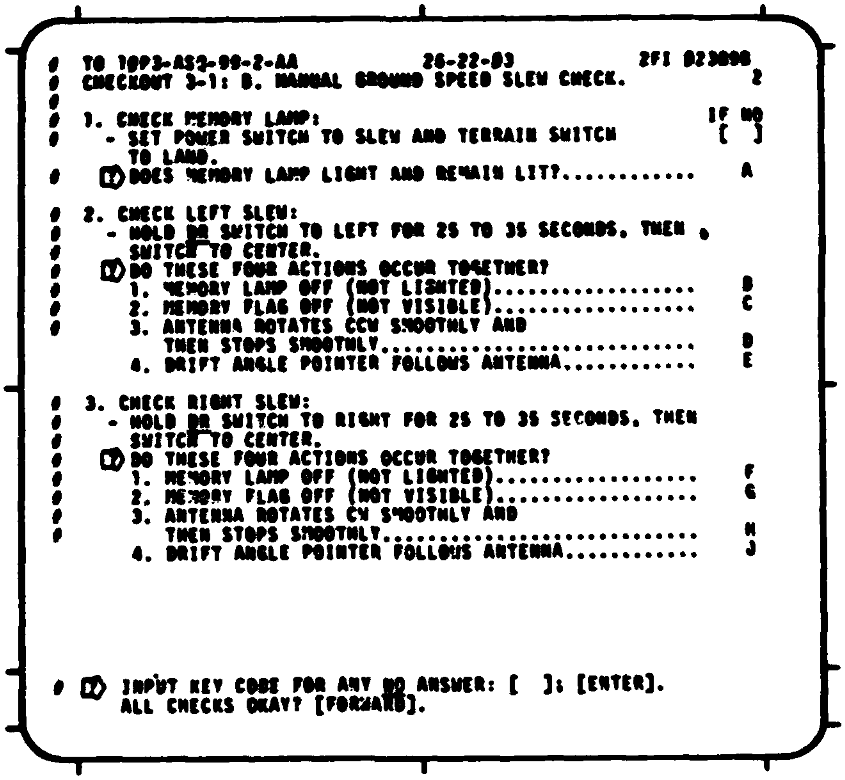


Figure 22. Track 2 Troubleshooting - Example of Checkout Frame.

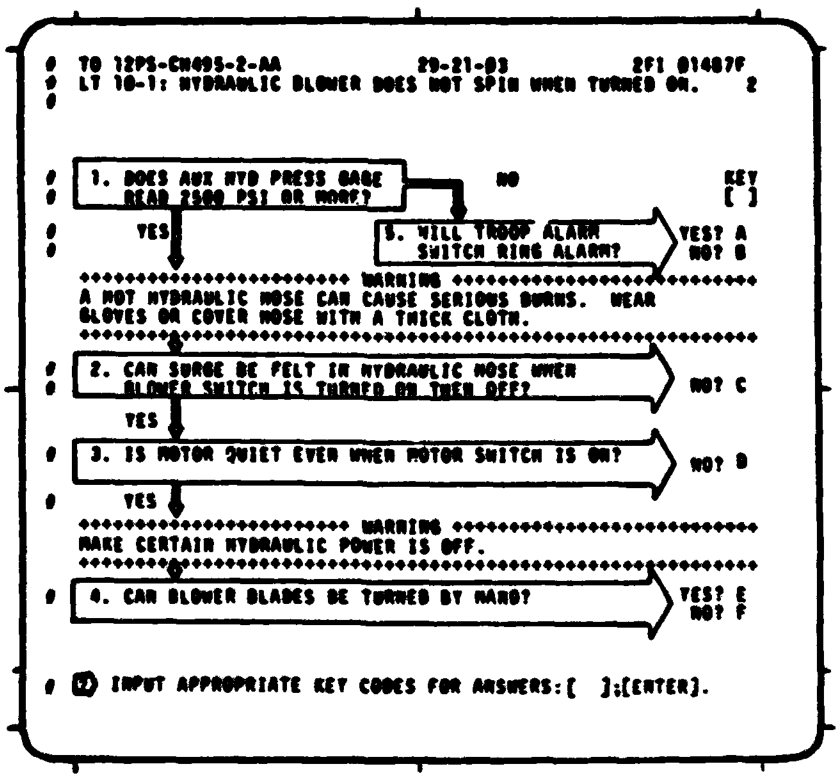


Figure 23. Track 2 Troubleshooting - Example of Logic Tree Frame.

troubleshooting tree. Instructions are presented with minimum detail based upon the assumption that the technician knows how to perform the basic tests. Additional detail may be provided for unusual or especially complex tests. Illustrations showing referenced components are not normally provided.

Track 1. The Track 1 troubleshooting procedures provide minimum detail. The level of detail provided is similar to that provided by a standard checklist. The Track 1 procedures include the following:

1. Input Conditions. The input conditions for Track 1 are essentially the same as for Tracks 2 and 3.

2. Warnings, Notes, and Cautions. This information is presented the same as for Tracks 2 and 3.

3. Checkout Procedures. The checks to be accomplished are listed in the order in which they are to be performed (see Figure 24). No guidance is provided on how to accomplish the checks or where the referenced components are located. The only assistance provided is an indication of what the expected status or indication should be. If the normal status is not found or an out-of-tolerance indication is found, branching to the proper fault isolation sequence can be obtained by entering the number of the failed check.

```
#  TO 5N1-3-8-2-AA                  34-60-00                 1FI 018420
#  CHECKOUT 3-1: A. POWER TURN-ON AND DISTRIBUTION.                    2
#
#  CHECK        COMPONENT                                NORMAL STATUS/
#  [ ]                                                    INDICATION
#
#     1  AIR NAVIG MULTIPLE INDICATOR FLAG........ VISIBLE
#     2  OFF/MAN/AUTO SWITCH...................... MAN
#     3  AIR NAVIG MULTIPLE INDICATOR FLAG........ NOT VISIBLE
#     4  NAVIG COMPUTER BLOWER.................... OPERATING
#     5  TEST HARNESS, 115V AC SWITCH............. OFF
#
#     6  CONTROL INDICATOR OFF INDICATOR.......... LIGHTED
#     7  TEST HARNESS, 115V AC SWITCH............. ON
#     8  TEST HARNESS, TEST POINT B12(HOT)........ 26 VAC
#     9  TEST HARNESS, TEST POINT E6(RETURN)...... 26 VAC
#    10  TEST HARNESS, HEADING TRACK READOUT
         BETWEEN TEST POINTS D6 AND D7............ PRECISE NULL



#     FOR FI DATA: INPUT FAILED CHECK NUMBER [  ]; [ENTER].
      FOR CONTINUATION OF BENCH CHECK: [FORWARD].
```

Figure 24. Track 1 Troubleshooting - Example of Bench Checkout Frame.

4. <u>Fault Isolation Procedures</u>. Track 1 fault isolation procedures are presented in a modified checkout format (see Figure 25). This procedure is based upon the same sequence as the logic tree. However, only the bare essentials of symptom identification and status information are provided. The possible faults are shown with each symptom. This format is similar to typical symptom/cause charts found in conventional TOs and specified by MIL-M-38800A. The difference is that they are based upon the logic of the LTTA.

```
TO 12PS-CH49S-2-AA                 29-21-03          1FI 02467C
LT 10-1: HYDRAULIC BLOWER DOES NOT SPIN WHEN TURNED ON.       2

CHECK                                      PROBABLE FAULT IF:
                                           YES       NO

1. AUX HYDRAULIC PRESS(2500 PSI)           -         -
   - IF LESS: TROOP ALARM RINGS            CIRCUIT   AUX DC PWR
                                           BREAKER

++++++++++++++++++++++++ WARNING ++++++++++++++++++++++++
   A HOT HYDRAULIC HOSE CAN CAUSE SERIOUS BURNS
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++

2. HYDRAULIC SURGE                         -         SOLENOID
                                                     CONT VLV

3. MOTOR QUIET                             -         SPLINE SHAFT

++++++++++++++++++++++++ WARNING ++++++++++++++++++++++++
       MAKE CERTAIN HYDRAULIC POWER IS OFF
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++

4. BLOWER TURNS BY HAND                    MOTOR     BLOWER




   FOR FOLLOW-ON DATA:[LIST OPTIONS].
```

<u>Figure 25</u>. Track 1 Troubleshooting - Example of Troubleshooting Data Chart Frame.

<u>Formats for Pool Data</u>

Formats are required to present a number of different types of pool information for presentation on the automated technical data system. Most of the data can be accommodated in basic formats without special features. For example, Theory of Operation information is primarily textual information and is presented in a basic text format. Other types of data, however, require special formats. Primary examples are IPB information and functional diagrams (e.g., schematics and block diagrams). Work was accomplished on formats for presenting all types of pool data. However, only the formats for IPB and block diagram formats are described in this report. The remaining formats are described in detail in Hatterick (1985).

<u>IPB Information</u>. Formats for IPB information are based upon the requirements of MIL-M-38807 (USAF) and are designed to permit access from the same starting points (e.g., knowledge of assembly or subassembly, part number, reference designator, etc.). Formats were developed for frames to present

listings of each type of information and for composite parts breakdown (CPB) frames. The listing frames serve a dual purpose. They are used to provide specific information (such as the reference designator associated with a given part) and to present menus which lead to the next level of listing or to the CPB for an assembly, subassembly, or part. The CPB frame provides detailed information on the subject part. The information includes the part number; reference designator; Source, Maintenance and Recoverability (SMR) code; Federal Supply Code for Manufacturers (FSCM); quantity per assembly; index number; use on code; and information on the relation of the part to the next higher and next lower assemblies. An illustration of the part is also provided. Examples of a CPB frame and a representative listing frame (part number index) are presented in Figures 26 and 27.

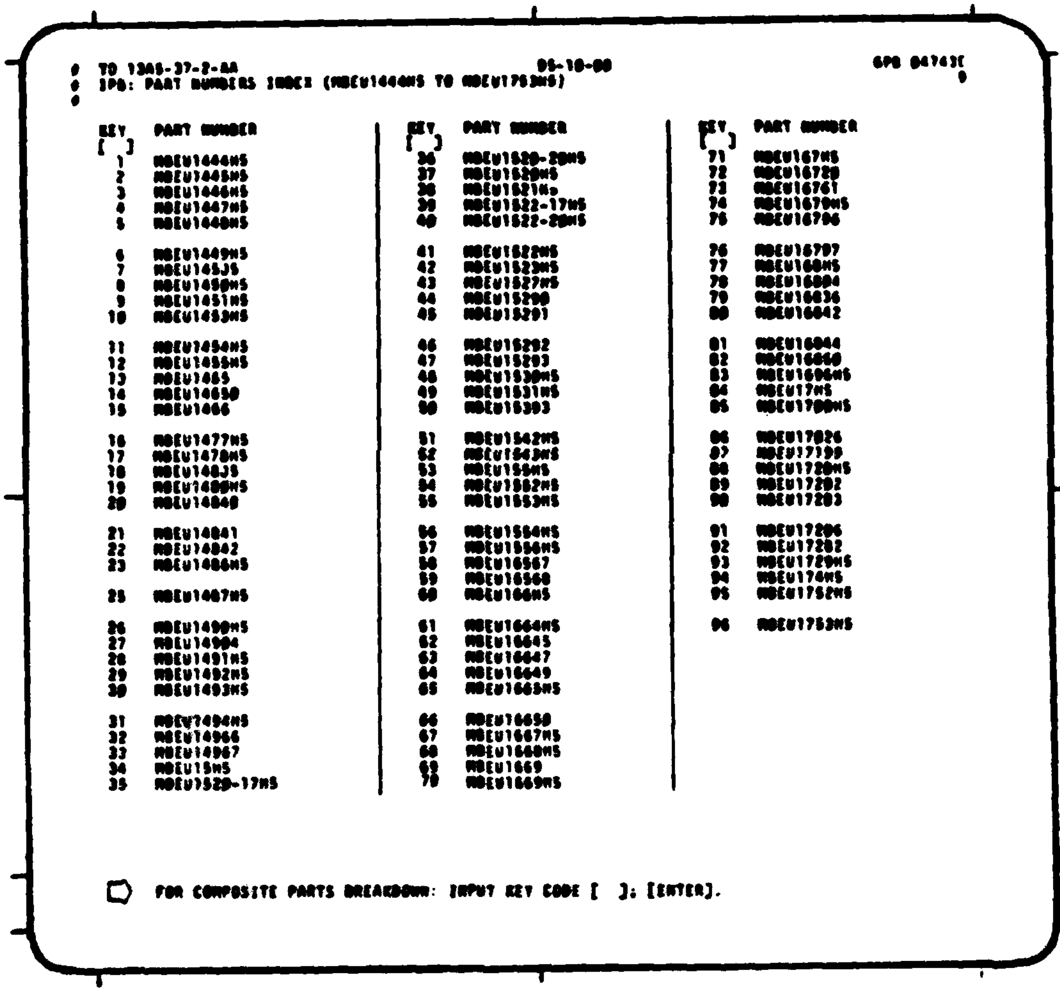


Figure 26. Example of IPB Part Numbers Index Frame.

Formats for Functional Diagrams. Functional diagrams provide a problem for presentation on a computer display since they are frequently too large to present on the screen in a legible manner. The simplest solution to this problem is to present only a portion of the diagram at one time. However, this presents a problem since the user must be able to comprehend the relationships between the portion that is seen and the portions that are not

seen. Even if the entire diagram is provided and the user is able to "move" the diagram to view different portions, he is likely to lose his orientation and become confused.

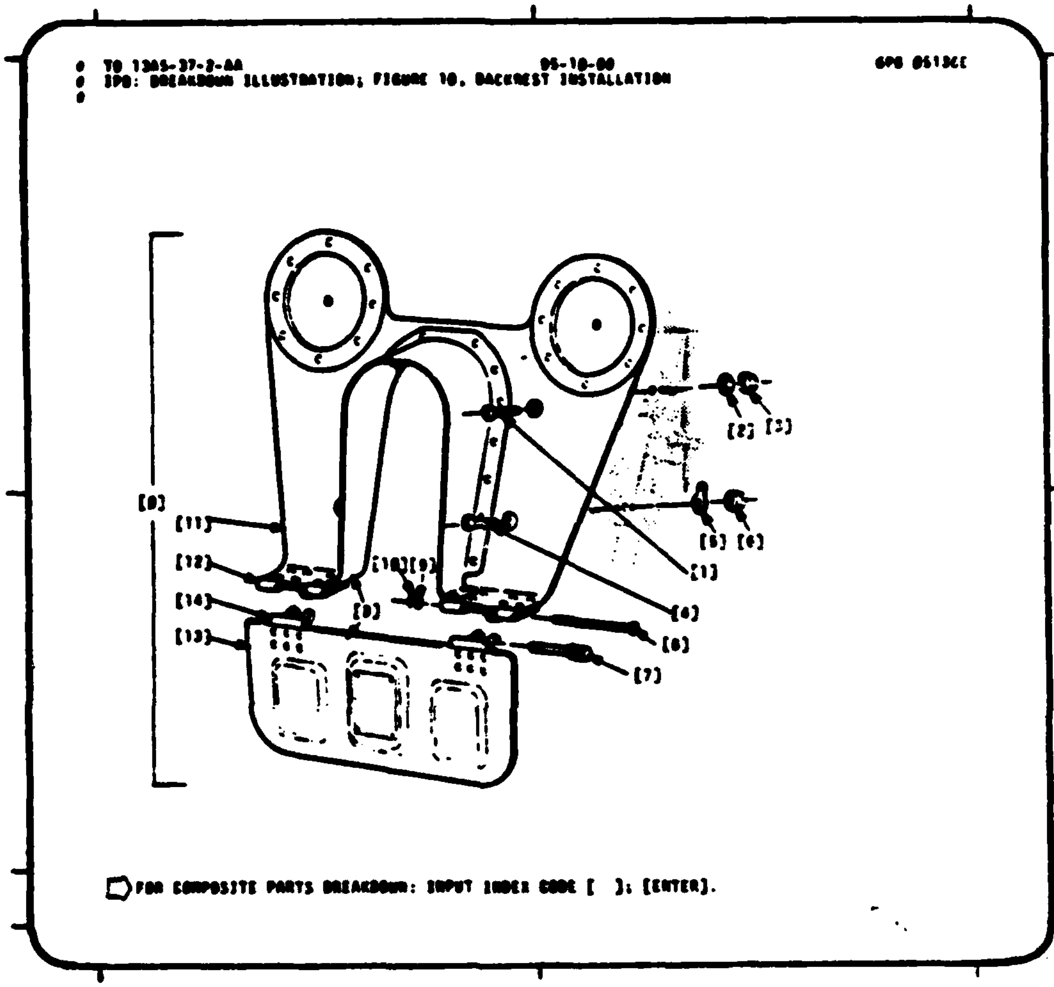


Figure 27. Example of IPB Composite Parts Breakdown (CPB) Frame (Exploded View of Simple Mechanical Assembly).

The approach taken for the prototype system to overcome the above problem was to use an orientation diagram to present the overall diagram with the basic functions and their relationships depicted (see Figure 28). The diagram does not provide detailed information on any of the functions shown. If the user desires detailed information on any of the functions, he inputs a code from the orientation diagram. A detailed diagram of the function is then displayed. Figure 29 shows the diagram that would be displayed if the user entered the code (4) from the diagram in Figure 28. If the user is interested in the interface between two functions, a different code will call up a diagram which provides details on the interface between the functions. The user is able to use the HOLD/SHOW functions to store and quickly recall each diagram for quick reference.

An alternative approach available to the user is to enter a code from the orientation diagram to obtain the complete basic diagram. The diagram is then displayed in readable detail, and is centered on the function selected. The user is then able to pan and zoom the display as desired.

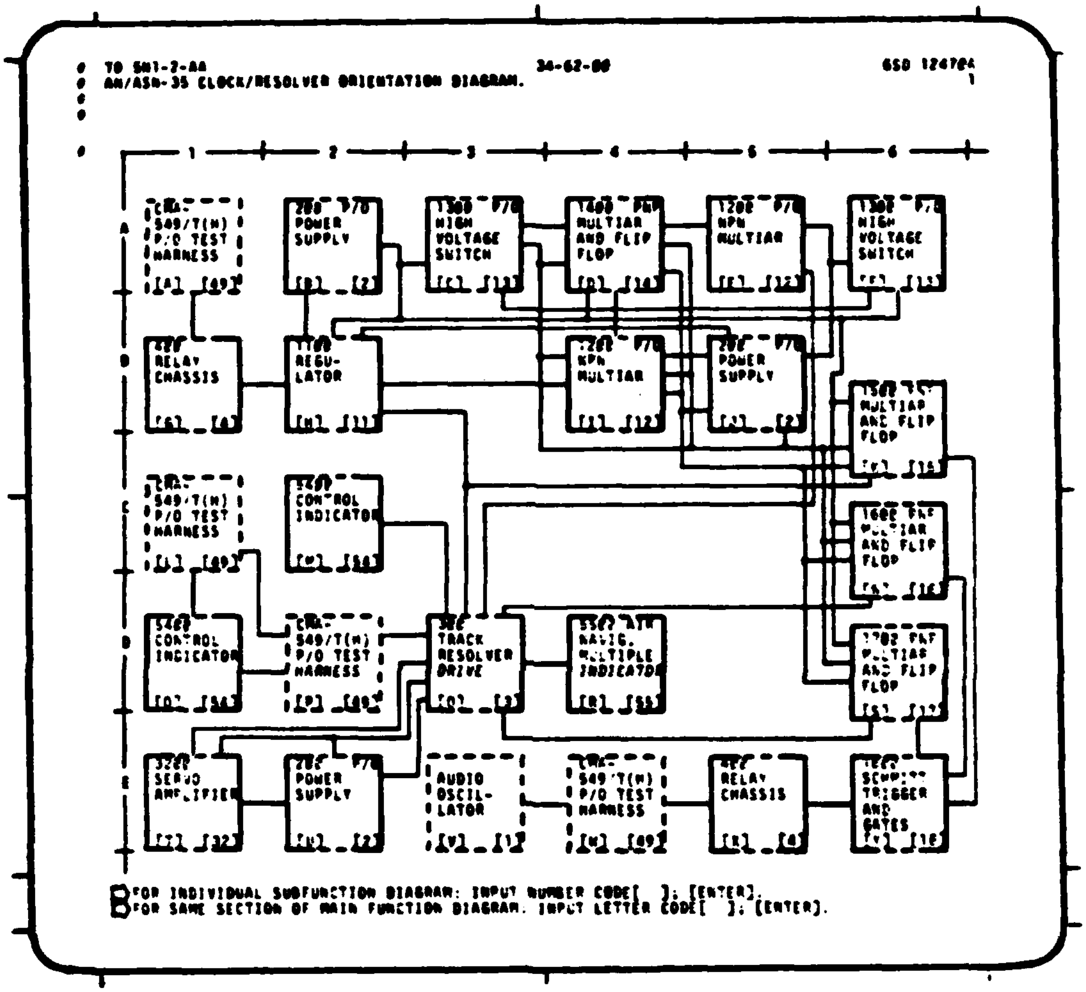


Figure 28. Example of Functional Diagram, Type 3 (Orientation Diagram of Complex Schematics).

Development of Maintenance Task Analysis Procedures

The Laboratory's earlier work in job performance aids research had recognized the need for a very high degree of accuracy in proceduralized technical data. This research led to the development of improved maintenance task analysis techniques for the development of technical data to ensure that the data are accurate. In developing requirements for the prototype automated technical data system, it was recognized that the capability to develop technical data with an extremely high degree of accuracy is essential. It was also recognized that development of automated technical data would provide some unique problems since new types of data and data interrelationships would

have to be considered. For these reasons, a requirement was included in the contract to revise and expand the task analysis procedures to support the development of accurate technical data for presentation on an automated system.

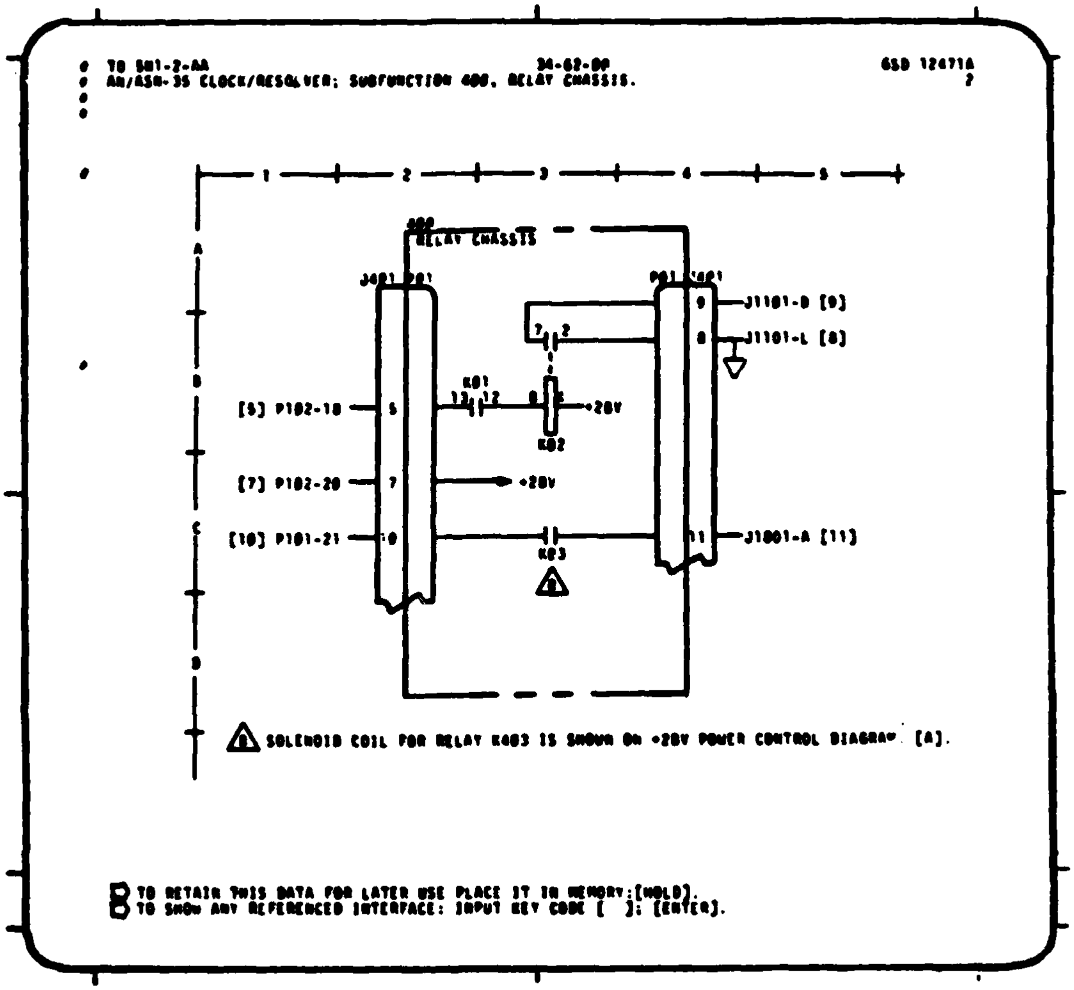


Figure 29. Example of Functional Diagram, Type 3 (Subfunction Diagram for High Complexity Schematics).

In preparation for revision of the task analysis procedures, an analysis was made of the unique requirements for the development of technical data. In addition, a review was made of existing task analysis procedures to determine what changes were necessary to accommodate the new requirements. A draft report describing the revised task analysis procedures was developed (Smith & Hatterick, 1979). The contract was terminated before the task analysis procedures could be completed or tested.

Identification of Software Requirements

Preliminary work on software requirements for the prototype system was initiated. Basic data base management software requirements and data access

strategies were studied. However, the contract was terminated before the requirements analysis and design could be completed. The work accomplished was not formally documented.

Identification of Hardware Requirements

Since this research occurred very early in the development of automated technical data systems, very limited guidelines were available on which to base the selection of hardware for the system. A review of available guidelines for the development of interactive information presentation systems was made to identify known requirements for such systems. However, there were several areas (e.g., display resolution for graphics) in which there was insufficient information to firmly establish hardware requirements. Since it was not possible at that time to establish firm hardware requirements, a decision was made to procure equipment with more capability than was expected to be necessary. This approach would make it possible to develop the prototype system under the "best conditions" and, once requirements were better understood, to determine the minimum hardware requirements for the system.

Based upon the above analysis, hardware was selected and ordered. The primary equipment items ordered were a VAX 11/780 computer system and a Megatek Model 7000 graphics terminal. The VAX had the capability to provide more than enough computational power to support the prototype requirements. The Megatek display is a high-resolution display (4096 x 4096 pixels on a 12 x 12 inch display) capable of displaying any graphics required for display on the prototype system. The computer and display were delivered to the contractor. The contract was terminated before the equipment could be installed. The equipment was diverted to another Laboratory project.

Discussion

The information provided above describes how the prototype system was designed to operate. However, since the system was not developed, the effectiveness of the design will never be known. The work accomplished in this effort provided much of the groundwork for systems that were developed later.

IV. CMAS I DEVELOPMENT AND EVALUATION

Following the termination of the Unified Industries effort, requirements for the CMAS program were reevaluated and the program was restructured. The revised structure placed an emphasis on determining the requirements for a CMAS system, including technical data presentation requirements, deployment requirements, MMI requirements, and requirements for interfacing with other automated information systems. It provided for the use of existing hardware and software, with some modifications, to develop a limited prototype to demonstrate and test the concepts. This approach eliminated the requirement to develop hardware and software specifically for the program as had been the approach in the Unified Industries effort. In addition, the B-1B Program Manager was in the process of determining technical data requirements for the

B-1B. The use of an automated technical data system was under consideration. A decision was made to orient the revised CMAS program toward the B-1B program to ensure that the specifications developed in the program would meet the requirements of the B-1B.

A contract was awarded on 1 December 1982 to Rockwell International with a subcontract to Hughes Aircraft Company. The major portion of the technical work was accomplished by Hughes Aircraft Company. Rockwell International provided management and expertise on the B-1B requirements. Additional contractual support for this effort was provided under subcontract by BioTechnology, Inc. BioTechnology provided consultation in the area of technical data requirements and human factors. BioTechnology had served in the same capacity on the Unified Industries effort. The results of this effort are discussed in this section.[2]

The contract provided for the definition of requirements for a CMAS to support intermediate level maintenance, development of a prototype system, and development of specifications. The system was to be:

1. Suitable for deployment in support of combat operations;

2. Compatible with requirements for the B-1B;

3. Compatible with the Automated Technical Order System (ATOS) under development by the Air Force Logistics Command; and

4. Capable of presenting of all types of technical data required for intermediate level maintenance.

The approach taken by the contractors was to first conduct detailed analyses of the requirements for the CMAS. The analyses included:

1. B-1B maintenance requirements analysis;

2. Deployment requirements analysis; and

3. Human factors and MMI requirements analysis.

One of the objectives of the analyses was to identify design issues for which there was not sufficient information available upon which to base design decisions. The next step in the program was to conduct a series of small design studies to specifically address these issues. Three design studies were conducted. After the design studies were completed, the design of the system was accomplished, the system was fabricated, and sample technical data were developed and input to the system. The system was then evaluated in field tests. Specifications were then developed based upon the results of the field tests and the earlier analyses.

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[2]The work performed under the contract is documented in two unpublished reports by Hughes Aircraft Company (1985a and 1985b). The materials presented on pages 57-71 and pages 73-82 of the present report are adapted from the Hughes reports. The remaining materials in this section were developed by the authors.

Design Goals

Based upon contract requirements and an analysis of system goals, the contractors developed a set of design goals. The primary goals identified are discussed below.

1. Cost. The cost of developing, procuring, and supporting the system must be minimized through the use of available technologies (off-the-shelf equipment, etc.) and the use of software designed for easy maintainability.

2. Performance. The system must enhance user performance by providing complete technical information in a manner that is matched to his knowledge and capabilities.

3. Modular Design. The design must be modular to permit easy update with new technological developments as they become available.

4. Generic Data Base. Data must be maintained in a generic data base to allow presentation using different display devices and formats without changing the data base.

5. Multimedia Capability. The system must provide the capability to present data via multimedia, including different types of display devices and paper.

6. Data Interface Definition. The design must provide for interfacing the system with other information systems such as ATOS and the Automated Maintenance System (AMS).

Design Issues

An extensive literature review was conducted to identify data presentation and MMI techniques which have been shown to be effective. The search revealed that the literature did not contain adequate guidance on several design issues critical to the design of the CMAS. Among the issues recognized were:

1. Data Access Methods. The most frequently mentioned data access methods were menus, fill-in-the-form or query, direct access by data identifier, and flexible search. However, there were no firm guidelines for selecting access modes for various applications. Research was needed to identify the most effective data access methods for automated technical data systems.

2. Presentation of Graphics. There were a number of issues related to the presentation of graphics for technical data.

a. Level of Detail. To minimize data storage requirements, it is essential that the amount of detail in graphics be limited to the minimum necessary to support the task. Adequate information was not available to permit an accurate definition of level of detail requirements or to provide a basis for developing guidelines to govern the development of graphics for use with automated technical data systems. Research was needed to establish

requirements for the levels of detail for various types of graphics to be presented via automated technical data systems.

b. Presentation of Complex/Large Graphics. Graphics that are too large to be presented on the display at one time present a special problem. Methods suggested for displaying graphics that cannot be displayed at one time included: scrolling, zooming, segmentation of the graphic by windowing, and storing the graphic as a set of hierarchical graphics. Research was needed to determine which techniques are the most appropriate for the complex graphics found in technical data.

c. Coding and Highlighting. A number of techniques have been suggested for coding or highlighting text and graphics. These include the use of color, blinking, increasing intensity of material to be emphasized, and reverse video. Research was needed to determine which of these is most effective for presenting technical data and under which conditions they should be applied.

Design Studies

After examining the design issues discussed above and after considering the capabilities of the available hardware and software and the costs required to add new capabilities, three design studies were agreed upon. Design Study 1 was a basic study to compare the performance of technicians on representative maintenance tasks using an automated system with their performance on the same tasks using the standard technical data. Design Study 2 examined techniques for presenting and highlighting complex/large graphics. Design Study 3 examined techniques for the presentation of text and graphics together. Different data access methods were not studied because the available software could support only one access approach (menu access). The design studies are described below.

Design Study 1

Purposes. The purposes of Study 1 were:

1. To provide a general demonstration of the features of the proposed system; and

2. To compare the performance of technicians using electronic and conventional paper-based technical data presentation methods.

Method. Six Air Force technicians (two highly experienced, two moderately experienced, and two inexperienced) served as subjects. Each subject completed two tasks, one with the electronic technical data and one with the paper-based technical data. The tasks were the removal of a shop repairable unit (SRU) from the assembly and the installation of the unit into the assembly. Tasks and type of data used were given in a counterbalanced order. The removal task, whether performed with paper or electronic technical data, was always done first by each subject. The electronic technical data were presented on hardware and software that were adapted from the Navy Technical Information Presentation System (NTIPS) developed by Hughes Aircraft with the sponsorship of the NTIPS program office. A black-and-white display terminal with 512 x 512 pixel resolution was used to display the data. The

instructions were presented in a format similar to that used for Job Guide Manuals with step-by-step instructions supported by illustrations of the referenced components (see Figure 30). The data were presented in three levels of detail (tracks). The technician was permitted to switch between tracks as desired.

The data collection sessions were videotaped so that the technicians' performance and interaction with the system could be analyzed. The times required to perform each task and the errors made were recorded during the analysis of the videotapes. Pre- and post-test questionnaires were administered to evaluate the technicians' attitudes toward the paper and automated technical data systems.

Results. The task selected for the study was judged by AFHRL observers to be too simple to provide an adequate evaluation of the system. Due to this problem and the small number of observations, a formal analysis was not made of the time and error data. Technical errors were very few and were not analyzed. However, it was observed that the time to perform each task using the electronic system was less than the time using the paper-based technical data. Analysis of the pre- and post-test questionnaire data indicated that, after the study, the technicians responded with more positive responses (statistically significant at the $p < .05$ level) to three of the items. They were: "A computer-aided system would help me do my job faster." "A small compact computer would be useful in my work." and "A rugged computer package would be useful in my work." There were more negative than positive responses for some questions. However, none of the differences was statistically significant.

Recommendations. The following recommendations were made, based upon the results of the study (Hughes Aircraft Company, 1985b, p. 3-11):

1. Pursue the development of the CMAS prototype, provide a greater range of display capabilities, and test the system using more complex experimental tasks.

2. Retain the three-track Job Guide format with interactive branching capability.

3. Retain the basic means of interacting with the system (i.e., NEXT and BACK keys, menu-driven selection of data, text and graphic windows for data presentation, an electronic terminal and keyboard for data entry).

Design Study 2

Purpose. The purpose of Design Study 2 was to identify optimal methods for presenting large, complex graphics via the electronic medium.

Variables. Four variables were examined in the study:

1. Color-Coding. Individual functional segments (i.e., groups of lines or symbols representing an electronic function) were identified. Each functional segment could then be displayed in color or in black and white with highlighting. The color condition consisted of displaying the functional

Remove transformer-rectifier from LVPS Assembly:

1.. Release five captive fasteners (2) that attach transformer-rectifier (1) to LVPS Assembly (3).

2. Take transformer-rectifier (1) out of LVPS Assembly (3).

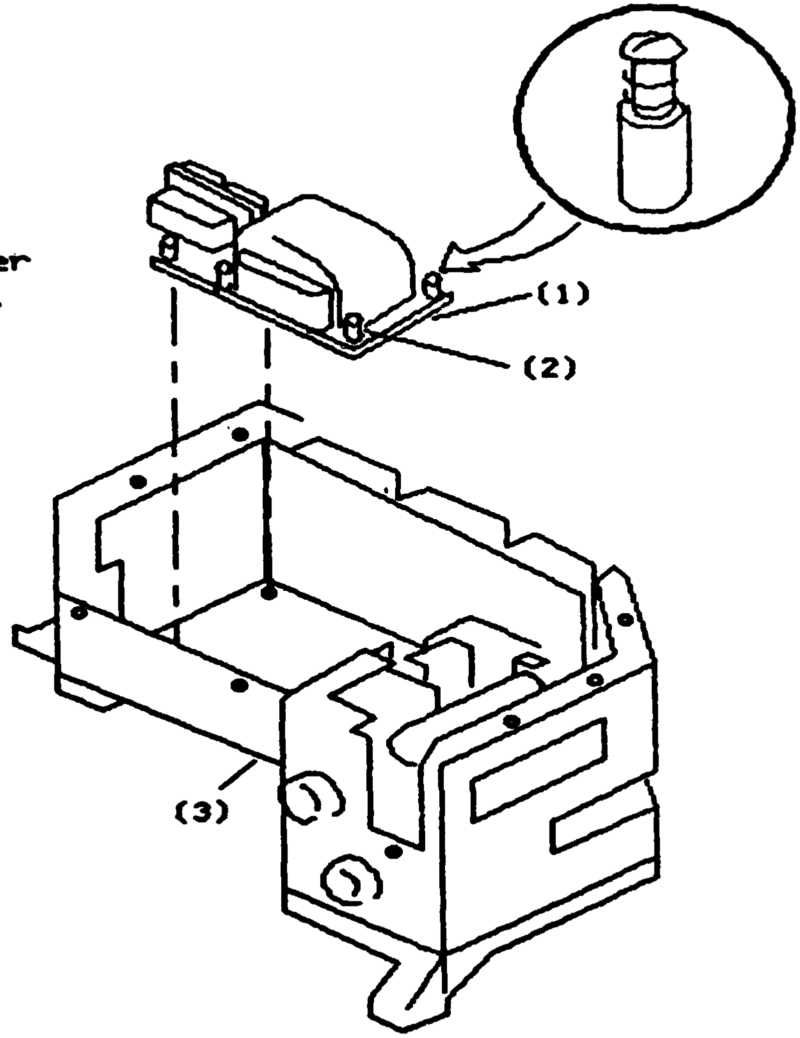


Figure 30. Example Frame (Track 2) Used in Design Study 1.

segments in different colors (up to 16 distinguishable colors). In the black-and-white condition, the diagram was initially shown using solid lines (black on white). By activating the pick-and-highlight function, the user was able to select a line or component. All of the lines and symbols associated with that element were then displayed with a dotted line.

2. Resolution. The resolution of the display is described in terms of the number of pixels which can be addressed across the display. Two levels of resolution were evaluated: high resolution (1024 x 1024 pixels) and low resolution (512 x 512 pixels). The same display was used for both conditions. Software was used to control the resolution level. The display size was 11.6 x 15.1 inches. The low-resolution level was typical for displays in use at that time.

3. Segmentation Method. Segmentation method refers to the method of breaking up large graphics into smaller elements which can be displayed at one time. Two methods were evaluated:

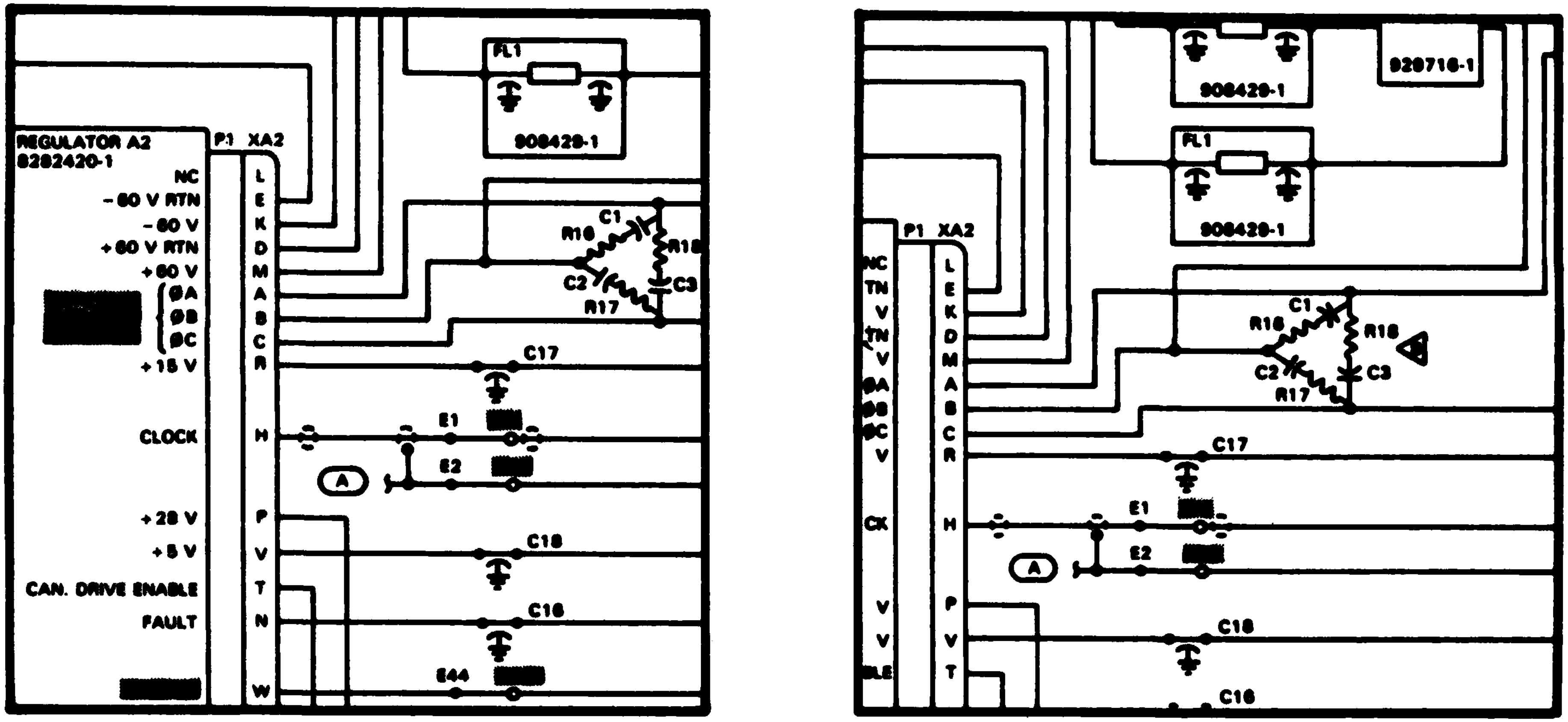
a. Spatial Segmentation. With spatial segmentation, the graphic is represented as a two-dimensional surface. The user can move a "window" (the display or portion of the display) over the surface allowing him to view portions of the graphic. The effect is similar to that of using a paper foldout where each unfolding reveals a portion of the drawing not previously seen. See Figure 31 for a representation of the spatial segmentation approach.

b. Functional Segmentation. In this method, the system is represented by a series of hierarchical diagrams based upon the functions of the components. The highest level diagram depicts the basic functions involved in the system. Each successive diagram provides a more detailed breakdown of one or more of the functions shown on the higher level diagram. As many layers as necessary may be used to break the functions down to their most basic structures. The diagrams are formatted to be viewable as a whole on the display. The user must view several screens to see the complete information at the detailed level. This approach is known as "pyramiding" and is similar to that used for paper technical manuals where foldouts are not desired. The pyramiding approach is depicted in Figure 32.

4. Graphic Interaction Mode. The graphic interaction mode refers to the type of commands the user can use to manipulate the display. Three interaction modes were provided:

a. Baseline mode. In this mode, the user was allowed to scroll and zoom selected portions of the display. The user was able to select an area of interest (e.g., a rectangle defined by diagonal corners indicated by the cursor) on the display. The system would then expand the diagram to fill the screen.

b. Pick-and-Highlight Mode. In this mode, the user was able to move the cursor to a selected line or symbol on the diagram and highlight the associated functional segment by pressing a key on the puck (or mouse). If the color condition was in effect, the selected segment would be displayed in red. If the black-and-white condition was in effect, the segment was shown in dotted lines. The scroll and zoom functions were also available under this condition.



512 GRAPHICS WINDOW – USER INPUTS SCROLL COMMAND

WINDOW MOVES TO NEW COORDINATES

Figure 31. Example of Spatial Segmentation (Scroll) of Schematic Information.

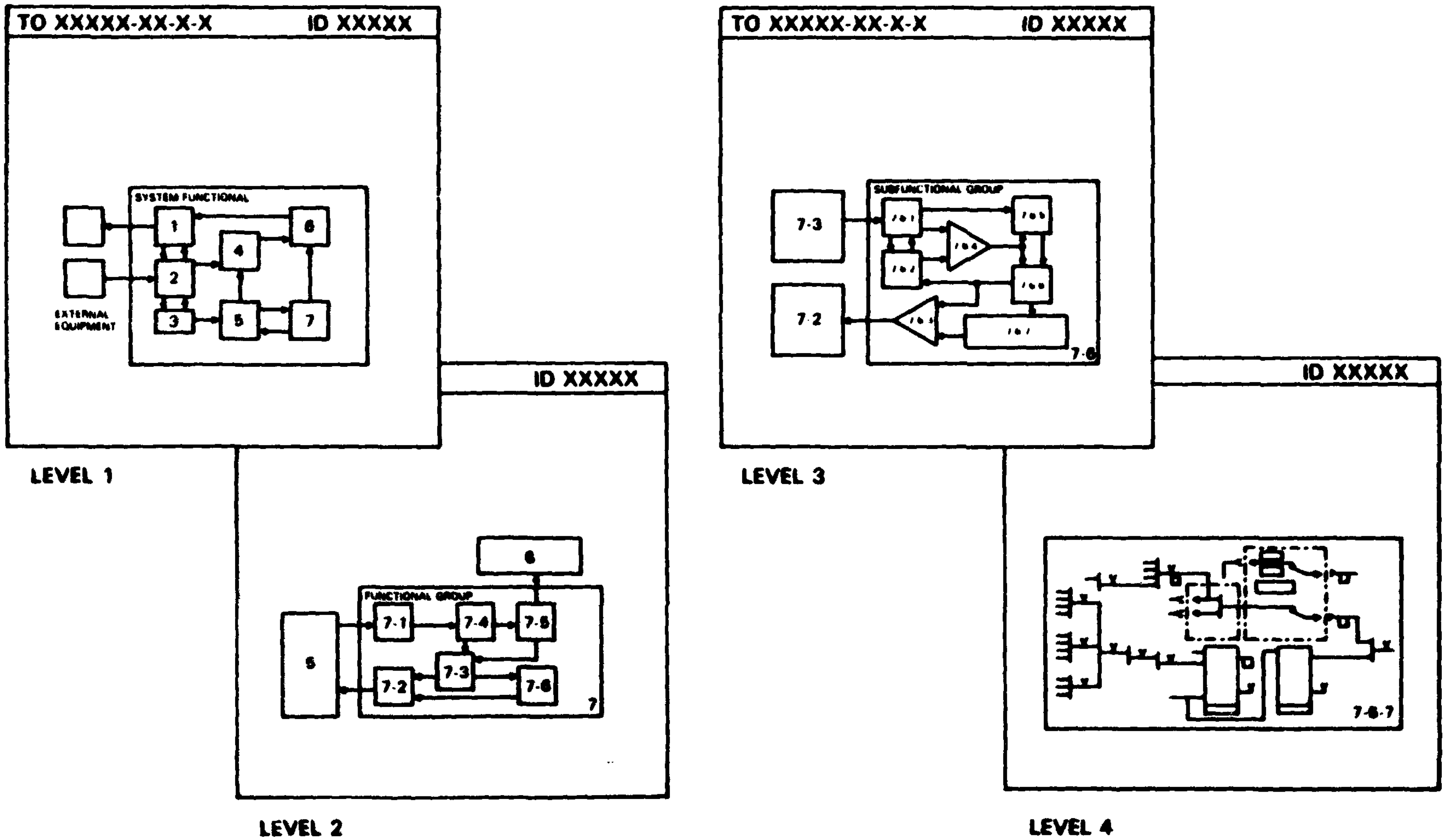


Figure 32. Example of Functional Segmentation (Pyramid) of Schematic Information.

c. Schema Mode. In this mode, the display was divided into two windows (upper half and lower half). A functional block diagram of the system represented by the schematic was presented in the upper window, and the schematic was presented in the lower window. The zoom, scroll, and pick-and-highlight functions were available for the schematic (lower window) but not for the functional block diagram (top window) due to limitations in the test system software.

Experimental Design. A split-plot factorial design was used. The color variable was the between-subjects variable. The resolution, segmentation, and graphic interaction conditions were fully crossed and were presented as repeated measures to all subjects. The order of the experimental conditions was randomized for the graphics interaction conditions. The resolution variable was presented in counterbalanced blocks. Six experienced Air Force technicians served as subjects for the study. Each subject completed 12 problems (representative troubleshooting tasks). Subjects tested during the first week were assigned to the color condition. Subjects tested during the second week were assigned to the black-and-white condition.

Test Data. It was determined that a complex schematic diagram represents the most difficult test of the capability of a system to present large, complex graphics. Schematics have many components, require electronic symbology and text, have many line elements that are close together, and require the user to have access to all parts of the diagram, either at one time or in sequence. A complex schematic diagram was selected as the stimulus material for use in evaluating the experimental data collection techniques.

Experimental Tasks. The experimental task was to perform simulated troubleshooting tasks on the receiver transmitter unit (RT-728A) of the AN/APX-64(V), Identify Friend or Foe System. An analyst identified 12 representative faults that can occur in three circuits of the unit. The tasks were judged to be equal in difficulty of fault isolation. The analysts then prepared a protocol which, given that the subject fault was present, listed the expected result of each possible test of the affected circuits.

Performance Measures. Several performance measures were used to evaluate the subjects' performance under each condition:

1. TOTAL - The total effective viewing time (total time graphics were on the display during the test period).

2. TIME - The mean effective viewing time used by the subject to actually view and interpret the data on the screen.

3. TS - Troubleshooting errors (including identifying wrong component as faulty, not identifying the fault at all, taking the wrong logical path, and not being able to interpret symbols or circuit functions).

4. SYSTEM - System errors (errors made in interacting with the system, such as incorrectly using NEXT, BACK, or a graphics function).

5. PROCEDURAL - Total number of instances requiring unplanned intervention by the experimenter to allow the subject to continue the task (e.g., system problems, technical data problems).

All time measures were calculated from observations of videotape recordings of the test sessions. Error measures were calculated from the notes of the experimenter, the observer (an AFHRL representative), and the videotape rater.

Experimental Procedure. The experiment was conducted at the Hughes Aircraft Company facility in Long Beach, California. A maintenance laboratory was used. The computer display was installed on a bench in the laboratory in a manner similar to that which would be used in an actual intermediate level avionics maintenance shop. Prior to the start of the experiment, the subject was asked to complete a short pre-test questionnaire. After a short training period on the use of the computer system, the technician was given the troubleshooting problem and instructed to identify the faulty component. The diagrams presented on the computer display were his only references for diagnosing the problems. Since "live" equipment was not available to actually make required measurements, the technician was instructed to tell the test administrator what tests he would like to make. The test administrator then gave him the expected result of that test as given on the test protocol. For example, if the technician indicated that he would like to "check the voltage at TP 5," the experimenter would respond (based upon the test protocol) that the output was "normal." After the testing was completed, each subject completed a post-test questionnaire and was interviewed to obtain his overall reactions, suggestions, and recommendations.

Results. An Analysis of Variance was performed on the data collected for each of the performance measures (total time, total viewing time, effective viewing time, and troubleshooting errors), the system measure, and the procedure measure. Analyses were also made to determine the effect of the order of presentation and to evaluate the comparability of the problems. The analyses yielded the following statistically significant results:

1. For the segmentation variable, the mean effective viewing times (TIME variable) required by technicians to perform the experimental tasks using pyramid functional/schematic diagrams were significantly less than the times required for technicians to perform the experimental tasks using spatial segmentation diagrams. This appeared to be due to the length of time required for successive redrawing of the diagram when the scroll feature was used to locate an item of interest or trace a signal flow. Since, in some cases, it was necessary to redraw the diagram several times to locate the items of interest or to follow a signal flow, significant amounts of time were lost waiting for the computer to display the correct portion of diagram.

2. A significant F-value was obtained for the PROCEDURAL measure for the schema, pick-and-highlight, and scroll and zoom (baseline) conditions (means .45, .20, and .16, respectively). The schema condition required the least intervention by the experimenter.

3. For the SYSTEM measure, a significant three-way interaction was found for the color x segmentation x graphics variables. This interaction was not interpretable.

Analysis of the questionnaire and debriefing data provided the following observations:

1. Technicians had generally more positive attitudes toward an automated technical data system following the experiment than before.

2. Technicians responded negatively to the two-window schema condition as implemented. However, they generally favored having an overview window available. They recommended the following steps to make the overview effective:

a. The overview window should be "active" and have all of the graphics capabilities (scroll, zoom, and pick-and-highlight).

b. The initial presentation of the overview diagram should be at a scale such that all text and symbols are legible.

c. Other technical data content should be selectable for presentation in the second window.

3. The color-coding condition was generally rated highly by the technicians.

4. The scroll condition was rated favorably by the technicians. Four out of six technicians rated it as easy to use. The "discontinuous" nature of the scroll function was not seen as a problem. (As implemented, when the schematic was scrolled, the display was erased and the schematic redrawn in the new orientation. The user could not see the schematics "move.")

5. The technicians rated the cursor control (puck) as acceptable. It was suggested that the function keys be included on the puck itself.

6. The menu used to select the graphics functions was seen as acceptable, but somewhat slow.

7. The technicians agreed that the response time (time from request until the frame was displayed) was too slow. Response times of 1 to 2 seconds were recommended.

Recommendations. Based upon the experimental data and the results of the questionnaire data and post-test interviews, Hughes personnel made the following recommendations (Hughes Aircraft Company, 1985a, p. 35):

1. The most critical finding of the study is that technicians are able to troubleshoot more effectively when using a series of hierarchical (pyramid) functional diagrams presented on a computer than when using one large schematic presented on a computer display and viewed using scroll and zoom functions. Therefore, the CMAS specifications should provide for the use of hierarchical or pyramid diagrams for the presentation of complex diagrams. In addition, the system should provide a rapid and simple method for selecting and displaying alternative diagrams from the pyramid set.

2. Statistically significant differences were not found for the Color, Resolution, and Graphic Interaction conditions. Therefore, these variables

could not be recommended for inclusion in the CMAS specification on the basis of this study. The subjects did not demonstrate significantly improved performance with the high-resolution screen nor did the presence of color reliably improve the performance of the technicians.

3. The hardware used for the study resulted in an unacceptably slow response time. A significantly improved response time is necessary for a production CMAS system.

The minimum capabilities for the prototype should include a black-and-white, 512 x 512 graphics display with zoom and scroll capability. The graphics data should be prepared in a pyramid format such that each subdiagram would be presented in one screen with lines, symbols, and text legible at first presentation, and with functionally grouped graphic elements available for highlighting.

Design Study 3

Purpose. The purpose of Design Study 3 was to evaluate the effects of: (a) integration and nonintegration of text and graphics, (b) the level of detail of graphics, (c) the use of color-coding, and (d) resolution of the display on the performance of selected nontroubleshooting, procedural tasks.

Variables. Four variables were examined in the study.

1. Integration Method. Two methods were evaluated:

a. Fully Integrated - Text was presented as an overlay to the graphic image such that the text appeared in close proximity to the referenced components. A callout arrow pointed from the text to the referenced component. The sequence of steps was indicated by numbering the steps. The text was subject to the same interaction functions as the graphic. The concept is illustrated in Figure 33. (A sample frame from the study was not available for inclusion in this report.)

b. Nonintegrated - The text and graphics were independent. The text was presented in a dedicated text window on the left side of the display and subject only to text manipulation functions. The graphic was presented in a dedicated window on the right side of the display. Callout arrows on the graphic were keyed to the text. The format was similar to that shown in Figure 30.

2. Color-Coding. Two color conditions were used:

a. Color Coded - Coding was based on the function of the component (e.g., connectors were presented in one color; screws were presented in another color).

b. Black and White - All components were shown in black and white.

3. Detail Level. Two levels of detail for presentation of graphics were evaluated:

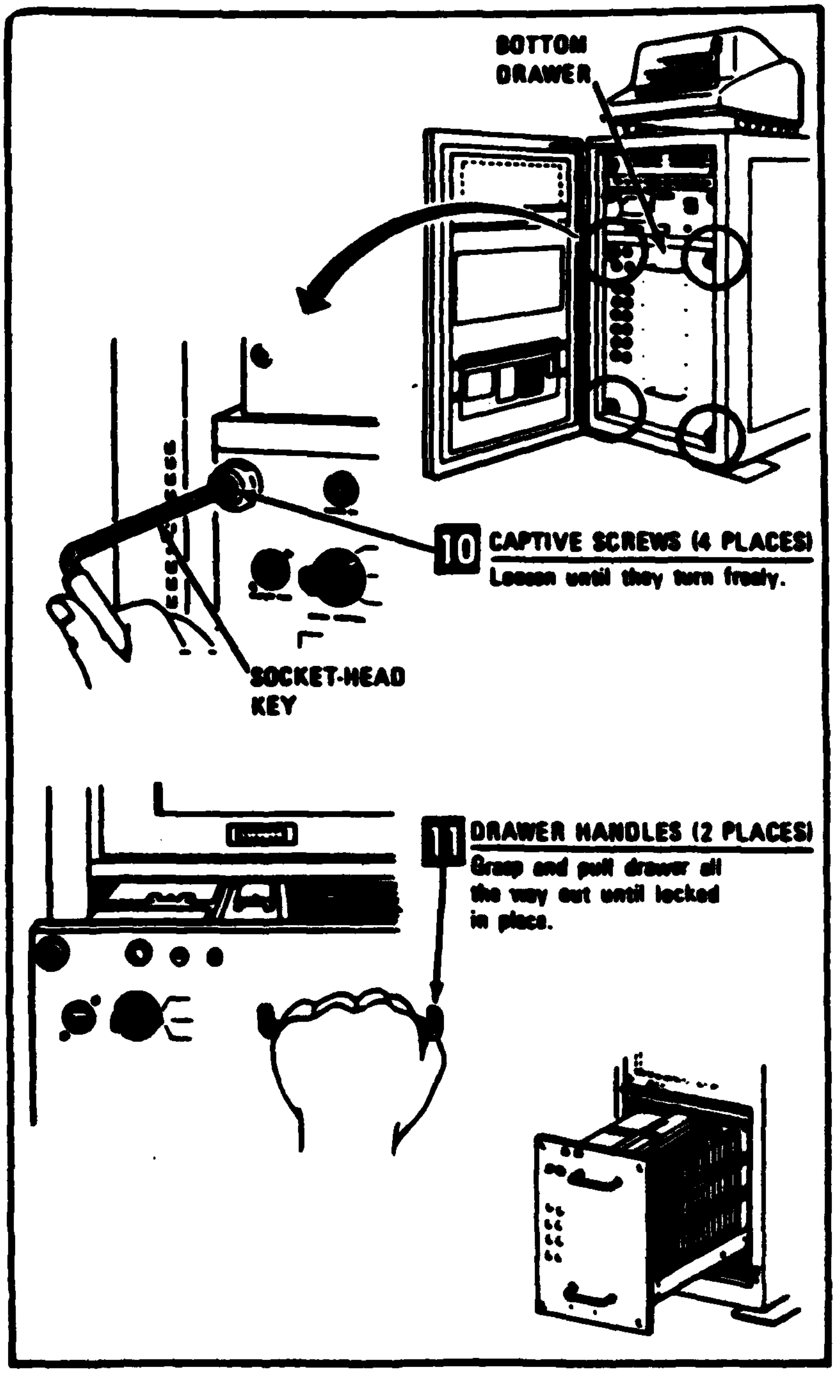


Figure 33. Example of Integrated Text and Diagnostic Concept.

a. High Detail - The graphics contained all of the detail provided in the original paper-based technical order graphics with the exception of shading, screw threading, connector detail, and textural detail. All parts were shown whether referenced or not.

b. Low Detail - The same basic graphic used for the high detail condition was used, with the exception that only the parts referenced in the text were shown. Nonreferenced parts which were part of the structural frame were retained but reduced to an outline.

Experimental Design. A split-plot factorial analysis of variance model with one between-subjects variable (resolution) and three repeated measures variables (color, integration method, and level of detail) was used. Each subject received eight experimental conditions. Random assignment was made to the resolution variable. Six Air Force technicians (three high-experience and three low-experience) served as subjects for the study.

Experimental Tasks. Four tasks for the maintenance of the RT-728A of the AN/APX-64 Identify Friend or Foe System were used as the experimental tasks:

1. Remove RF Module
2. Install RF Module
3. Remove Diode from the RF Module
4. Install Diode in the RF Module

Experimental Procedure. The experimental procedure was the same as that used in Design Study 2. The pre- and post-test questionnaires used in Design Study 2 were administered. In addition, a new questionnaire relating to the specific features evaluated in this study was administered following the testing period. The experimental tasks were performed in the maintenance laboratory used for Design Study 2. The workbench and computer display were set up in a similar manner. The subject's performance was observed by the experimenter, who took notes on performance errors, deviations from experimental procedures, system problems, etc. The sessions were videotaped.

Performance Measures. The following performance measures were used:

1. TOTAL - The total effective viewing time (total time graphics were on the display during the test period).

2. TIME - The mean effective viewing time used by the subject to actually view and interpret the data on the screen.

3. MAINTENANCE ERRORS - The number of errors observed by the experimenter during the test. These included performing the wrong action, using the wrong tool, performing actions in the wrong sequence, and orienting parts in the wrong way.

4. SYSTEM - System errors (errors made in interacting with the system, such as incorrectly using the computer commands NEXT or BACK or a graphics function).

5. PROCEDURAL - Total number of instances requiring unplanned intervention by the experimenter to allow the subject to continue the task (e.g., system problems and technical data problems).

In addition, the initial level of detail selected by each subject was recorded for each trial. The number of track changes was also recorded. All time measures were calculated from observations of videotape recordings of the test sessions. Error measures were calculated from the notes of the experimenter and the videotape rater.

Results. Analysis of variance techniques applied to the performance measures yielded one statistically significant main effect. A statistically significant F-value ($p < .05$) was found for the TIME measure for the color condition. The mean effective time required to perform the experimental tasks was 104.1 seconds under the color condition and 117.8 seconds under the black-and-white condition.

Statistically significant main effects were not found for the resolution, detail level, and integration method variables. However, the authors (Hughes Aircraft Company, 1985a) noted that

> ...the means for the effects suggest that subjects performed faster whenever there was less visual information on the screen. Low resolution (103.7 seconds) was less than high resolution (118.1), and low detail (99.5) was less than high detail (124.5). The fully integrated mean (98.9) was less than the non-integrated mean (125.0). However, further research is required to determine whether actual effects are associated with these observed values. (p. 49)

No statistically significant differences were observed for the MAINTENANCE ERRORS measure and the TRACK CHANGES measures.

The results of the questionnaires were generally consistent with the findings from Design Study 2. Four of the six subjects were interviewed following the test. Significant observations from the interviews included:

1. All subjects felt that the most detailed level (Track 3) was patronizingly simple. The less detailed Track 2 was preferred. It was recommended that the complexity of tasks be considered in determining whether two or three tracks of technical information are required.

2. All subjects were able to use the zoom with little, if any, difficulty. The zoom capability was used primarily to enlarge the step text for the integrated test condition. The zoom capability was recommended for the prototype system.

3. The scroll feature was not used by any of the subjects.

4. The subjects were split in their opinions on the value of color-coded graphics. Two subjects preferred the color condition. The other two subjects did not feel that there was any difference in the readability of the color and monochrome graphics.

5. The subjects stated that they were unaware that some trials were performed under high-resolution conditions while others were conducted under low-resolution conditions. There did not appear to be any significant difference in the usability of the high- and low-resolution presentations. Readability seemed to be more a function of the absolute size of the data on the screen than image resolution. It was recommended that the lower-resolution display (512 x 512 pixels) be used for the prototype.

6. All subjects found the low detail graphics to be more usable than the more detailed graphics. Low detail graphics were recommended for the prototype system.

7. All subjects complained that the time required to download graphics to the terminal was too long. It was recommended that the prototype system provide for much faster download times (although no specific recommendations were given by the subjects).

8. The subjects generally agreed that the experimental tasks were too easy to adequately test the system's delivery features. It was recommended that more challenging tasks be used for future tests.

Discussion and Recommendations. The researchers made the following recommendations (Hughes Aircraft Company, 1985a, p. 50) based upon the experimental data, questionnaire responses, and post-test interview comments:

1. The most significant finding of the study was the effect of color on the mean effective performance time. This finding was interpreted to mean that functional color-coding of equipment parts on isometric illustrations facilitates performance of procedural maintenance tasks. The functional specifications for the CMAS prototype should include the requirement for encoding of a maximum of 16 discriminable colors and for the functional coding of isometric illustrations such that equipment parts may be identified as functional units.

2. Further research is needed to assess the effects of: (a) integration of text and graphics in procedural instructions, (b) the effects of detail level of graphics, and (c) resolution. The type and complexity of the procedures and graphics used in the study did not place stringent enough requirements on the system to adequately evaluate these variables.

3. There were negative ratings of the CMAS as implemented in the design studies due to hardware limitations which resulted in very slow response times. This finding was consistent for all three studies. Minimum response times and maximum baud rates between host computer and graphics processor should be required for any CMAS configuration in the subsequent phases of the program.

4. The experimental procedures used in Design Studies 2 and 3 were very complex. A number of procedural irregularities occurred. Thus, caution should be used in generalizing from the results of the studies, as discussed below.

Comments on Design Studies

The design studies provided useful information for the design of the CMAS prototype and provided valuable experience for the system developers. However,

they did not provide the type of definitive design information that had been desired. A number of weaknesses in the design and implementation of the studies make it necessary to use caution in generalizing from the findings. The following paragraphs illustrate the problems/weaknesses of the studies.

1. Experimental Tasks. The experimental tasks selected for Design Studies 1 and 3 were much too simple to adequately test the variables being evaluated. The tasks were simple remove and replace tasks. An experienced technician (and even a novice with a good mechanical aptitude) would have been able to successfully perform the tasks without using technical data. The tasks were very simple, requiring only a few easy steps (as evidenced by the fact that the mean time to accomplish each task was less than 2 minutes). As a result, the ability of the system to provide the technician with instructions on how to do the task had little impact on performance. Similarly, the ability of graphics to aid in locating components on the equipment was not truly tested. There were no hidden, unique, or hard-to-find components that the technician needed assistance in finding. Further, the components illustrated were relatively simple and did not present the number of parts or the complexity often encountered in technical data.

2. Hardware/Software Limitations. The limited capabilities of the hardware and software available placed significant constraints on the studies. The system was able to provide all of the required functions. However, it was not able to provide the response times required for effective presentation of technical data. This was especially a problem for complex graphics such as those used in Design Study 2. Several minutes were required to draw some of the graphics. Similar delays were experienced in zooming and scrolling the display since these actions required redrawing. This forced the use of an approach to zooming and scrolling which involved erasing the screen and redrawing it several seconds later. The delay increased the risk of the user losing his place. The impact of this limitation on the results of the spatial segmentation versus functional segmentation schematic diagrams comparisons in Design Study 2 is not known. Similarly, the impact of response speed on the acceptance of the automated technical data system concept by the technicians is not known.

3. Sample Size. The sample size for the studies was too small. Only six subjects were used for each study (availability of subjects was limited by travel funds). With such a small sample, a relatively large difference in means is required to demonstrate a statistically significant difference in performance. As a result, the study may have failed to detect meaningful differences in the effectiveness of some of the variables studied. Hindsight suggests that more meaningful results might have been obtained had the studies been combined and all 18 subjects experienced each condition.

Perhaps the most significant finding of the design studies was that, in spite of the problems, the concept of automated technical data systems was well received by the technicians. They were willing to overlook the weaknesses of the test system because they could see the potential benefits of an automated system (with the identified weaknesses corrected). Other significant findings include: (a) the apparent advantage of the "pyramid" approach for presenting schematic diagrams, (b) the apparent advantages of color-coding for schematic diagrams and possibly for functional coding of

equipment drawings, (c) the value of keeping presentations simple by eliminating unnecessary detail, and (d) the apparent lack of any need for a resolution level higher than 512 x 512 pixels (on the 11.6 x 15.1 inch display). Further testing of these features is essential before firm requirements can be established. The tests should evaluate the features in a wider variety of applications and more challenging situations.

Man/Machine Interface Design

Based upon the results of the literature surveys and the design studies, the contractors developed a proposed MMI design for the CMAS. The proposed design represents what was felt to be necessary for the most effective system. All of the features specified were not included in the prototype system for a number of reasons. The basic MMI requirements (Hughes Aircraft Company, 1985b, pp. 3-49 through 3-52) are described in the following paragraphs:

Graphics Display Mode Function. The graphics files must be displayed in various ways through the selection of the display functions listed below. Each function must be associated with a data table of options. All options must be selectable. (The purpose of the graphics display mode is to provide several alternatives to the user for test and comparison of the effectiveness of graphics presentations under a variety of conditions.)

1. Window Definition - The user must be able to define portions of the display screen (e.g., 1024 x 1024 pixel array subdivided into rectangular areas) for display of portions of the graphics data base. Window size and placement must be definable, not fixed.

2. Viewports - The user must be able to define the portion of the graphics data base or file to be displayed in a given window.

3. Graphics Files - The user must be able to define and display multiple portions of two or more files in multiple windows.

Resolution. The user must be able to select either low or high (512 x 512 or 1024 x 1024 pixels) resolution for the full screen. (Resolution was controlled by experimenters, not users, during the studies.)

Character Size. The user must be able to select either a character size appropriate for a close viewing distance (2 feet) or character size suitable for a far viewing distance (6 feet) (character heights of .13 and .21 inch, respectively) for standard text elements of the graphic. (Not implemented.)

Interactive Processes. The user must be able to input commands at the keyboard to:

1. Enter text to an overlay plane to annotate portions of the graphic. The text file must be associated with the user's identification code, and must be retrievable by the user for display at a later session. (Not implemented.)

2. Pick graphic segments by indicating position with cursor or coordinate commands.

3. Scroll and zoom by moving a viewport over the graphics data base. Relative movement of a window must appear to the user to be a window moving over a fixed graphic in response to user inputs (e.g., cursor command to go left moves the window left relative to the graphic which appears fixed).

Scroll must appear as a movement of the window left/right and up/down at a rate of approximately 10 frames per second and a displacement of .25 window widths per frame. (Not implemented to simulate continuous scroll due to slow refresh rate.) Zoom must appear as an increase or decrease of image size within the displayed window at a rate of approximately 10 frames per second and a change of .25 window widths per frame. (Not implemented to simulate continuous zoom due to slow refresh rate.)

Fabrication of the CMAS Prototype

The next task was to fabricate the prototype CMAS for use in the field test. The approach was to take the hardware used in the design studies, the NTIPS software, and the special software developed for the design studies, and to adapt and expand them to meet the MMI requirements--to the extent that resources, technical capabilities, and time constraints would permit.

The hardware configuration is presented diagrammatically in Figure 34. The system was composed of the following hardware:

- MODCOMP 7840 Computer System (host system) with a MAX IV resident operating system, hard disk drives, and tape drive.

- CONRAC Model C3919NPL High Resolution Color Graphics Display (1024 x 1024 pixels).
- Rastertech Model One/80 (modified) graphics processor.
- Microframe translator and keyboard processor.
- Detachable keyboard.
- Mouse.
- Parallel Interface between MODCOMP and Rastertech.

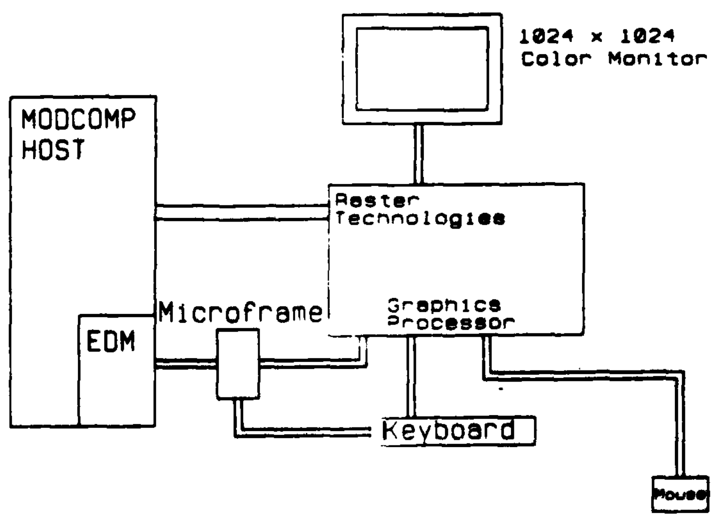


Figure 34. Prototype Hardware Configuration.

The following software was incorporated into the system:

- Existing NTIPS Electronic Display Module (EDM - hosted on MODCOMP), modified to satisfy CMAS Display Program software specification requirements.

- Color graphics display module (hosted on Microframe) developed to control interactive display of 512- or 1024-pixel resolution graphics and advanced features.

- Parallel interface software to increase speed of graphics data transfer.

- Fault Isolation by Nodal Dependency (Find) software modified to operate with the EDM.

- SIMPLER software package to control user interaction processes.

- Other special purpose software such as drivers to interface hardware, and special graphics manipulation techniques.

A number of problems were encountered in fabricating the prototype. Some of the problems prevented satisfying all of the MMI requirements specified above. Some of the problems were:

1. Response time requirements for data containing graphics were not met. The problem was due to several factors, including the fact that several time-consuming conversions of the graphics between the host computer and the display were required.

2. A continuous Scroll and Zoom feature was not possible. Continuous scrolling and zooming would have required extensive modifications to the CMAS graphics display system and separation from the MODCOMP host system.

Technical Data Development

The next step in the program was to develop a set of technical data for a representative testbed system for use in evaluating the CMAS. Technical data were developed for portions of the Receiver/Transmitter unit (RT-728A) of the AN/APX-64 Identify Friend/Foe System. The AN/APX-64 is used on several Air Force aircraft including the KC-135. The procedures used, problems encountered, and recommendations developed from this task are summarized below.

Front-End Analysis

A detailed front-end analysis (FEA) was conducted to ensure that the data developed were complete, technically accurate, and written at a level of detail appropriate for the intended users. The FEA included the following analyses:

1. Detailed Task Analysis. A systematic analysis was undertaken to identify each task performed on the subject equipment to ensure that all tasks were covered; to identify the information that the technician requires to do

each task; to establish a list of distinctive and convenient common names for use throughout the data; to identify required supplies, parts, support equipment, etc.; and to develop effective procedures to accomplish each task.

2. Detailed User Analysis. A thorough analysis of the anticipated capabilities of the users was made to develop a description of the user. The description was provided to the technical data writer as a guide to ensure that the data were written at an appropriate level of detail. Since the data were to be written in three levels of detail, it was necessary to consider the capabilities of three categories of technicians (novice, experienced, and highly experienced) in the analysis.

The results of the above analyses were then used to develop guidelines for determining the amount of detail of the instructions written for each track.

Technical Data Development

Following the FEA, the following types of technical data to be used in the field evaluation were developed:

1. Corrective Maintenance. The corrective maintenance data were developed in a modified Job Guide format in three tracks. All tracks included illustrations (isometric graphics), warnings, cautions, notes, input conditions, tolerance values, and data access options. Track 1 provided general descriptions of the task. Track 2 included step-by-step instructions. Track 3 included step-by-step instructions plus descriptions of special techniques, identification of tools for each step, and other information required to aid an inexperienced technician in completing the task. The graphics were interactive. The user was able to scroll, zoom, and highlight areas of the graphic.

2. Troubleshooting Procedures. The FIND system was used to develop and present troubleshooting procedures. Schematic diagrams, wiring diagrams, voltage tables, and other data were analyzed to develop the parameter data needed for input to the FIND model. The FIND model uses component, signal, and dependency information to generate troubleshooting procedures by computer. The FIND procedures were presented in three tracks. Track 1 included symptom summary tables from the FIND model. Track 2 included test requirements identified by the FIND model. Track 3 included test requirements identified by the FIND model, along with illustrations for test point location and procedures for performing the tests. In addition to the track data, schematic diagrams were developed. The schematics were developed in the spatial segmentation format used for Design Study 2. Color-coding was used to identify functionally related components. The schematics were available to the user as pool data.

3. Illustrated Parts Breakdown Data. The IPB data were developed with little additional analysis. The primary task was to organize and format the data for input into the CMAS. The IPB data were presented in the form of complex isometric graphics. The graphics provided sufficient detail to allow the user to recognize individual parts. The graphics also served as a graphic index, in that the user was able to enter a code or callout number from the

graphic and retrieve the pertinent information relevant to the component of interest. The user was able to access parts information in the following ways: (a) He could select the appropriate graphic from a menu and then use the graphic as a menu to select information on specific components; (b) he could select a table of part numbers or reference designators and call up a graphic showing the item of interest; or (c) he could use a direct access mode to call up a graphic and parts information by directly entering the part number or reference designator.

It should be noted that, due to cost considerations, technical data produced for the field test did not incorporate many of the design criteria identified in the system design developed earlier in the effort. Points of deviation included:

1. Three-track data were available only for materials covered in Section 9 of the TO (Intermediate Frequency Amplifier). The checkout procedure and pool information were presented with only one track. Also, it proved to be very difficult to develop three distinctively different tracks for the testbed data. In most cases, it was difficult to develop a more enriched instruction for Track 3 than that provided for Track 2. For example, it is difficult to enrich an instruction to "Turn ON/OFF switch (1) to ON." The convention adopted to provide enriched Track 3 data was to specify the tool to be used. This information frequently was obvious and unnecessary. For example, even the technician with no experience does not need to be told to use a screwdriver to remove a screw. Another example from Track 3 data was the instruction "Using hands, turn ON/OFF switch (1) to ON." Such superfluous instructions were considered to be a joke by the technicians.

2. The functional segmentation approach identified as superior in Design Study 2 was not used. The spatial segmentation method with functional color-coding was used in its place.

3. The locator illustrations used with procedural tasks contained every callout used for any step in the data base. The earlier guidelines had indicated that only those callouts referenced on that specific frame should be shown.

4. Pool information (other than schematics which were color-coded) was not restructured for presentation on the CMAS. Information such as theory of operation, system description, test equipment, and special tools listings, etc. were copied verbatim from the TO.

Validation of Technical Data

Validation of the technical data was accomplished as described below.

1. Validation of Corrective Maintenance Data. Validation of the corrective maintenance procedures was accomplished at the Hughes Aircraft Company, using equipment provided by AFHRL. Validation consisted of successful completion of 100% of the procedures to be used in the field test.

2. Validation of the Troubleshooting Data. The troubleshooting procedures were validated at March AFB, California. Validation was accomplished

by completing all troubleshooting procedures using an active test bench in the intermediate level shop at March AFB. The FIND system was validated by using it to successfully fault-isolate a sample of faults at the system (line replaceable unit) level (80% of the faults were high-frequency-of-occurrence faults and 20% of the faults were selected at random). The validation was accomplished using a black-and-white terminal connected by modem to the host computer at the Hughes facility.

3. Illustrated Parts Breakdown Data. The IPB data were validated at the Hughes facility by Hughes' subject-matter experts. Validation consisted of comparing the electronic data with the original TO.

4. Pool Data. The pool data, consisting of schematics and theory of operation data, were validated at the Hughes facility by Hughes' subject-matter experts. Validation was accomplished by comparison of the data with the TO.

5. System Validation. The validation of the integration of the data and the CMAS was conducted at the Hughes facility by Hughes Aircraft Company, Rockwell International, and AFHRL personnel. The validation consisted of successfully accessing a sample data base in accordance with realistic maintenance scenarios and successfully locating the information required to perform the maintenance tasks specified in the scenarios.

Conclusions from the Data Development Task. Experience in the development of technical data for the CMAS led the contractors to the following conclusions and observations:

1. Three-Track Procedural Data. Procedural data cannot be developed in three tracks for all types of data and applications. The establishment of tracks and level-of-detail standards must be based upon the nature and complexity of the equipment being described. Task complexity, more than user characteristics, drives the need for multiple-track data and is the basis for determining the number of tracks required for a particular application. Electronic systems tend to be very complex to troubleshoot and simple to repair. Thus, for these systems, multitrack presentation may be required for troubleshooting. Procedural repair tasks do not seem to require multiple levels of detail. Mechanical systems, however, present a different set of documentation problems. The fault isolation and repair processes are not neatly separated, but are closely related. In addition, mechanical systems are more complex to disassemble, inspect, and repair. Multitrack data are appropriate and necessary for such systems. Nonetheless, it is hardware complexity rather than user performance potential that is the primary driver in determining the need for a multitrack approach.

2. FEA Requirements. All data base planning was found to depend completely on a comprehensive FEA which defines, in detail, all data requirements. This provides a firm basis for planning and managing the data development process. In addition, it enables the procuring activity to more effectively monitor the contractor's data development process. An FEA should be mandatory for the procurement of technical data for automated systems such as the CMAS.

3. Content Specification. It is essential that existing detail or content specifications be modified, or new specifications be generated, to

provide specific requirements for automated technical data for use at the various levels of maintenance.

Field Test

The field test was conducted at Offutt AFB, Nebraska, 5 November 1984 through 11 January 1985. Facilities of the 55th Reconnaissance Wing were used for the test. A number of problems were encountered in conducting the test which prevented accomplishing the field test as originally planned. A substitute evaluation approach was developed and implemented by AFHRL personnel. The original field test plan, the work accomplished under that plan, the substitute plan, and findings of the test are discussed below.

Field Test Plan

The original test plan (Hughes Aircraft Company) provided for an operational field test in which the CMAS system would be placed in an intermediate level shop responsible for maintaining the testbed system. The CMAS was to be made available for use by the technicians for their normal, day-to-day maintenance of the system. It was to be used to perform troubleshooting and corrective maintenance tasks as the requirements occurred. Data were to be recorded by the technicians on the use of the system and problems encountered in using it. Pretest questionnaires were to be administered to all personnel in the Radar Shop, the technicians were to use the system for a period of time, data were to be logged on the use of the system, and questionnaires and interviews were to be administered at the end of the test period. The plan did not provide for a more formal experimental test using performance tests. Hughes personnel had the primary responsibility for data collection under this plan.

As a result of problems encountered in implementing the original test plan, it was determined that an adequate evaluation could not be achieved by depending upon use of the system for actual maintenance tasks. A substitute plan was developed and implemented by AFHRL. This plan provided for the use of "set up" problems to provide a means of collecting limited performance data and to ensure that the technicians had an adequate opportunity to experience using the system. Twelve technicians (six high-experience and six low-experience) served as subjects. Each subject completed four problems: two using the CMAS and two using the paper TO. The problems included two checkout tasks, and two remove and replace tasks.

In effect, two concurrent evaluations were conducted. The initial plan was implemented by Hughes to the extent feasible. The second plan was implemented by AFHRL. The results of each evaluation are summarized in the following paragraphs.

Hughes Evaluation

Problems Encountered. Problems were encountered from the start of the test which made a bad impression on personnel in the Radar Shop and made it

impossible to adequately evaluate the system using the original test plan. The following paragraphs outline the problems encountered.

1. System Installation. The CMAS hardware was installed at Offutt AFB, Nebraska, on 5 November 1984. Installation was uneventful. However, the system required much more space in the Radar Shop than anticipated. The hardware consisted of a cabinet-mounted central processor unit, two pedestal-mounted disk drive units, a cabinet-mounted tape drive unit, and the Rastertech unit (located on a table). These units required approximately 50 square feet of floor space, which necessitated a rearrangement of a major section of the shop. In addition, the monitor was installed on a shelf above the workbench. The keyboard and mouse were placed on the workbench itself. The addition of these items to the workbench limited work space.

2. Heat Generation. The computer hardware required for the CMAS prototype generated an excessive amount of heat. The heat made the shop uncomfortably warm. In addition, it may have created equipment reliability problems.

3. System Unreliability. The system proved to be very unreliable. This appeared to be the result of three problems: (a) the effect of the heat on the hardware, (b) software problems, and (c) errors in the technical data. The unreliability of the system made it very difficult to use the system since it frequently "froze" making it necessary to reinitialize the system and start over. This was very frustrating to the technicians and a major contributor to their reluctance to use the system.

4. Response Times. The response times for the system were very slow. An average of 11 seconds was required to retrieve and display a frame of data with procedural steps and locator diagrams. Large, complex illustrations (such as schematics) required up to 2 minutes.

5. Technical Data Errors. The technical data contained an excessive number of errors. The errors included both technical errors and sequencing/access errors (e.g., branching to the wrong frame). These errors caused the technicians to lose confidence in the data and be reluctant to use the system.

Hughes Questionnaire Results. As part of their evaluation, Hughes personnel administered pre- and post-test questionnaires to the technicians in the Radar Shop. The questionnaires were of the Likert type, requiring the respondents to indicate their degree of agreement with a statement on a 7-point scale (strongly agree to strongly disagree). Analysis of the questionnaire responses yielded the following observations:

1. Technicians reported that the system increased job completion time.

2. Technicians agreed with the statement "I felt restricted by the computer." This feeling was thought to be due to insufficient access options to allow movement within the data base. The slow response time was also suggested as a possible contributor to this problem.

3. The system's response time was too slow to meet the user's needs.

4. The technicians did not have trouble reading the text on the screen. The legibility of the text and callouts were rated positively by the technicians. The character size used for the system was judged to be appropriate for the application.

5. The technicians rated the zoom feature as helpful.

6. The technicians rated the schematic detail (readability after zooming) as very helpful. It was recommended that schematics be presented so that they are initially legible (as in a pyramid format) or easily zoomed for legibility.

Hughes Interview Results. At the end of the field test period, six technicians who ha[illegible] the system were interviewed by Hughes personnel. The interviews yie[illegible]nts in the following areas: computer software, computer hardware, and technical data organization.

The following observations were made concerning computer software:

1. Technicians found the CMAS sign-on procedures easy to use.

2. Technicians found the menu method provided to locate data in the system to be acceptable. Five rated it as "good," and one rated it as "fair."

3. The "x-search" feature, which permitted the user to retrieve parts information by typing in the first 8 characters of a part number or reference designator, received a mixed reaction. It was rated from "fair" to "very good."

4. The "graphic menu" provided for location of parts information was rated "good" by four of the five who used it. Comments included "too many parts," "some errors," and "want overview diagram." The general response was interpreted to be favorable for the concept, but improvements are required for implementation.

5. Technicians expressed a need for a feature which would return the user to the point last displayed in the procedure after additional information had been accessed or displayed.

The following observations were made relating to computer equipment:

1. All six technicians indicated that they would prefer dedicated function keys, labeled with their functions and always available to the user.

2. The technicians all agreed that the keyboard was too large (taking up too much space on the workbench). Also, they did not like the mouse as implemented. Five recommended the use of a joystick to control the cursor. Hughes recommended a full-size keyboard for system and data base maintenance and a smaller special purpose keyboard with function keys and a joystick or mouse with function keys for use on the workbench.

3. Technicians' comments suggested a need for some method of reducing the glare on the screen and improved placement of the display.

The following observations were made relating to technical data organization:

1. Although the response speed of the system was seen as the major drawback in user acceptance, user acceptance of the use of color, system resolution, letter font, spacing, and viewing distance was good.

2. Technicians had mixed reactions to the three-track concept (as applied in the CMAS prototype). Two stated that Track 3 (most detailed) was "useless." Another could see no need for Tracks 2 and 3.

3. All technicians preferred to have only those callouts in the graphic that are referenced in the procedure. As implemented, the graphics contained all callouts whether or not the callouts were referenced in the frame (see Figure 35).

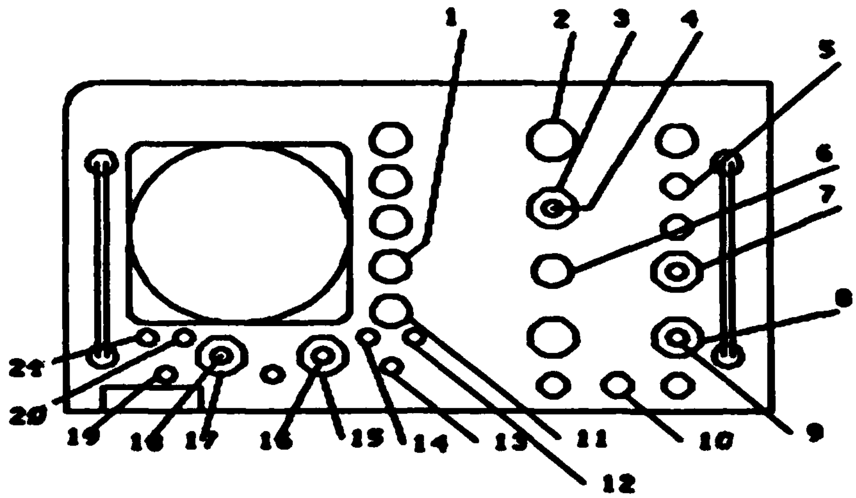


Figure 35. Example Locator Diagram with All Callouts Shown.

As a result of the problems discussed above, the CMAS prototype system failed to achieve acceptance by the technicians. This resulted in the technicians' being unwilling to use the system for their day-to-day maintenance of the testbed system, as required to implement the original test plan. It was decided that an alternate approach would be required to adequately evaluate the system and obtain the maximum benefit from the study. A substitute evaluation plan was then developed by AFHRL, and the Hughes evaluation was limited to posttest interviews and questionnaires which were collected following the AFHRL evaluation.

AFHRL Evaluation

Prior to implementation of the AFHRL evaluation, AFHRL personnel conducted a thorough review of the data presented on the system in an effort to eliminate as many errors as possible from the data. Technical errors were corrected by Hughes personnel.

Procedures. With the assistance of an experienced technician, four problems were identified which could be used for the test. Problem selection was based upon the following criteria: (a) the task could not require more than 1 hour to complete; (b) accurate data for completing the task must be available in the CMAS data base; (c) the task could be accomplished without damage to the equipment (since there was not time to obtain dedicated equipment or spares for the test); and (d) tasks for each category (checkout and remove/replace) must be comparable in difficulty and time to complete. Two checkout and two remove/replace tasks were selected. The checkout tasks involved performing the checkout procedure until two sensitivity out-of-tolerance conditions were identified. The remove and replace tasks involved removing two circuit boards from the intermediate frequency (IF) module. The tasks were judged to be adequate to give a general indication of the ability of the CMAS to support the performance of maintenance on the testbed system. However, it did not provide a thorough test of the system and its ability to support maintenance. The problems did provide technicians with sufficient experience on the system to permit them to provide their personal evaluation of the system and recommendations for improvements.

Each task was performed by 12 technicians. Six of the technicians were classified by a supervisor as having high experience on the system, and six were classified as having low experience on the system. Each technician performed one checkout and one remove/replace task with the CMAS, and one checkout and one remove/replace task with the paper-based technical order. The tasks were performed using the Shop's test bench for the AN/APX-64. Testing was done on a noninterference basis. Testing conditions were "semi-controlled" in that the test subject was isolated so interference was limited as much as possible. However, some interruptions did occur due to the shop environment and duties of the technicians. The performance of each technician was observed by one test administrator who noted problems, evaluated performance, and recorded performance times. Performance times were adjusted to account for delays from interruptions or system problems. Each technician was allowed to continue work on the task until completion or until he gave up.

Questionnaires were administered to the technicians following the completion of the performance tests. The questions were open-ended.

Performance Test Results. Data were collected on successful completion and time to complete each task. All subjects were able to successfully complete each task. The times to perform each task are shown in Table 4. Mean performance times for each task are shown by group (high versus low experience). The times to perform the tasks using the CMAS were longer in most cases than for paper TOs. There is very little difference in the mean times shown for the checkout task for the high-experience group. Examination of the individual times indicates that this is due to the excessive time for one individual when using the TO. This can be explained by the fact that the individual was a supervisor with several years of experience on the system. He had not actually worked on the system for some time. He performed the task first with the TO. This served as a refresher for him and probably aided his performance with the CMAS. If the performance time for this individual for that task (checkout using the TO) is eliminated, the mean times for the high-experience group are 29.6 minutes with the CMAS and 15.8 minutes with the TO.

Table 4. Task Performance Times (In Minutes)

Subject	CO/CMAS	CO/TO	RR/CMAS	RR/TO
H-1	45.00	8.00	5.00	5.00
H-2	13.00	14.00	9.00	4.00
H-3	32.00	13.00	4.00	8.00
H-4	35.00	11.00	7.00	7.00
H-5	37.00	95.00	8.00	4.00
H-6	23.00	33.00	14.00	5.00
Total	185.00	174.00	47.00	33.00
Mean	30.83	29.00	7.83	5.50
L-1	58.00	24.00	14.00	6.00
L-2	38.00	14.00	12.00	6.00
L-3	32.00	25.00	7.00	7.00
L-4	30.00	34.00	10.00	11.00
L-5	58.00	·15.00	14.00	4.00
L-6	52.00	12.00	6.00	7.00
Total	268.00	124.00	63.00	41.00
Mean	44.67	20.67	10.50	6.83
Grand total	453.00	298.00	110.00	74.00
Grand mean	37.75	24.83	9.17	6.17

Note. *H = high experience; L = low experience.*

The data presented in Table 4 are provided to give a general idea of the impact of CMAS on performance. However, caution should be used in generalizing from these data due to the lack of rigor in the test procedures. A formal inferential statistical analysis was not made of the data since there were sufficient irregularities (interferences, etc.) in the data collection procedures that assumptions required by formal analysis procedures could not be met.

Questionnaire Results. Analysis of the technicians' responses to the questionnaire yielded the following observations:

1. Of the 11 technicians who completed the questionnaire, 10 stated that the system response time was too slow. One indicated that he believed using the system could be faster than using the TO if the system response time were faster.

2. The technicians found that the readability of the display was satisfactory. The font sizes used to present textual materials and to identify callouts were considered acceptable.

3. Six of the technicians found the mouse easy to use. Three said it was hard to learn to use or was confusing. One simply did not like the mouse.

4. The zoom feature was found to be useful by most technicians. Only one technician reported any difficulty in using the zoom feature.

5. The scroll feature received mixed reviews. Only one technician rated it as "good." Other comments included: "it is impractical" or "not needed"; "it is too slow"; "couldn't figure it out"; and "scrolls backward."

6. Eight of the technicians indicated that the highlighting feature was helpful. One found it hard to use and two did not use it.

7. The techniques for accessing the data received mixed reviews. Some felt that they were convenient and easy to use. Others felt that it was too difficult to get from one place to another in the data base.

8. Reactions to the use of color on the system were mixed. Most found it to be "acceptable" or "good." Some indicated that it is not necessary for this type of system.

9. The resolution of the display was rated "good" or "adequate" by all of the technicians who responded.

10. Glare on the display was seen as a problem by most of the technicians. However, five of the technicians indicated the use of a shade adequately alleviated the problem.

11. The arrangement of the display, keyboard, and mouse on the workbench was seen as a problem by many. The location of the display on a shelf above the workbench was considered satisfactory by most technicians. However, several suggested repositioning it to reduce glare and to improve ease of viewing. The keyboard and mouse were seen as taking up too much space on the workbench, making the workbench too cluttered. Several suggestions were offered, including the use of a smaller keyboard with only required functions provided, the use of voice control, and the use of a joystick in place of the mouse.

12. The level of detail of the graphics was rated "adequate" by eight of the nine technicians who responded to the question. One indicated that the graphics needed depth.

13. The use of three levels of detail (tracks) received mixed reactions. Five of the nine subjects who answered the question indicated that the multiple levels of detail were helpful. The remaining four did not believe so. Six of the eight subjects who indicated a preferred track selected Track 2. Two stated that they preferred Track 2. None of the technicians preferred Track 3; however, two indicated it would be useful as a training aid or for someone with no experience.

14. When asked if using the system caused fatigue, six technicians indicated that it either caused no fatigue or caused no more fatigue than the paper TO. Three indicated that they experienced some eyestrain. One noted that "it probably could get to me after awhile."

Other Observations

Throughout the field test period, AFHRL personnel on-site continually observed the use of the system to identify problems, potential solutions, and

possible improvements of the system. Their observations were provided to Hughes personnel to solicit their comments and, when possible, to modify the system. The principal comments/problems/recommendations provided to Hughes personnel are provided below.

1. Graphic zooming is limited to the size and shape of the window. Most graphics are oblong rectangles. Thus, when an object is zoomed, it is forced into the (same) oblong window (regardless of the shape of the object to be zoomed). The result is that the drawing becomes distorted. This is true for both schematics and equipment. (For example, this situation occurs when a square area of the schematic or a square object in an equipment drawing is zoomed and forced to fit into a rectangular window.)

2. If the graphics mode is used (which allows scrolling and zooming), the system returns to the start of the module (start of the procedure) when exiting, regardless of where the graphics mode was entered. As a result, the user may be forced to page through several frames to get back to where he started (where the graphics mode was entered).

3. In the zoom mode, the system will zoom each time button #1 on the mouse is pressed. Button #2 must be pressed to get out of the zoom mode. If the user forgets and tries to recall the menu (by pressing button #1) without pressing button #2, the system will attempt to zoom an infinitely small area. The system will freeze, forcing the user to reset the system and start over.

4. In the graphics mode, if the "display full screen" option is selected, the graphic (which was designed for an oblong rectangular window) is distorted. (The full-screen display window is square.)

5. When a graphic is presented, an option is given to "manipulate the graphic." The user is instructed to enter "Y" to manipulate the graphic. The system does not say what to do if the graphics mode is not wanted. Any other key will clear the graphic mode (although the user is not told this). This means that any other key must be pressed, and then NEXT must be pressed to go to the next frame. A problem occurs when the user is in a branching frame and must respond "yes" or "no." If the user forgets to clear the graphic question and answer "yes," he is forced into the graphics mode. Then, when the graphics mode is exited, the user is returned to the start of the module and must page through several frames to get back to where he began.

6. There is no way of directly accessing a schematic without paging through the Theory of Operation section of the TO.

7. In many cases (such as Theory of Operation), an individual graphic (such as a block diagram) supports several frames of text. However, the graphic cannot be manipulated until the user has reached the last frame of text. Thus, if the user wants to manipulate the graphic to examine the drawing to answer a question brought about by the first frame, he must page to the last frame. Then the text is not available for reference. This could be a problem since many of the drawings (block diagrams, schematics, etc.) are not readable as initially presented.

8. Several frames are required to present some blocks of text. If an attempt is made to backspace before reaching the end of the block (end of module), the system will freeze, forcing the user to reboot and start over.

9. The formatting of procedural frames is inconsistent. Some present a full page of steps; some only one or two steps per frame. Some use tables to present cable setup instructions; others present the setup procedures as a set of step-by-step instructions.

10. The use of color-coding in equipment drawings makes it difficult to distinguish some components (due to poor contrast).

11. The equipment drawings contain callouts for every component, regardless of whether the item is called out in the frame of the procedure. Thus, the technician must search through all of the callouts to find the ones of interest. Some of the drawings are quite cluttered with callouts.

12. Many of the equipment drawing callouts are too small to be read easily. In one case, the callouts appear as "dots" and are completely illegible. If the zoom is used to read the callout, the drawing is distorted. Then, when the graphic mode is exited, the user is returned to an earlier part of the procedure and must page through several frames to return to where he started.

13. With the exception of checkout procedures, troubleshooting procedures, and some IPB information, the technical data on the system are direct copies from the Technical Order. Thus, with these exceptions, the system is simply a "page-turner," not much different than AFHRL has strongly opposed in the past. One of the prime goals of the program has always been a system that is more than just a page-turner.

14. Drawings, schematics, block diagrams, etc. are not identified. This is not critical for procedural data, but it is for other types of data. For example, Theory of Operation contains text with a block diagram at the bottom of the frame. The diagram is not identified. Therefore, the user cannot be sure what it is.

15. Many illustrations supporting procedural text do not have the option of manipulating graphics.

16. Many frames have too much text (i.e., the frame is full of unbroken text). This makes it difficult to read and increases eyestrain.

17. There is no direct access to "pool data" as originally required. If a technician using a procedure wants to view a schematic, he must exit from the procedure, go back to the table of contents, find the appropriate section, and then page through the section until he finds the schematic (which is not labeled).

18. The MIDAS coding system is not used as required.

19. The frames are not labeled. The user cannot tell where he is in the system. This could be a problem if the user is interrupted and goes back later, or if a new technician takes over part way through the task. If he is in a section that has multiple tracks, he cannot be sure which track he is in.

20. The mouse is very awkward to use.

21. To switch tracks within a procedure, the user must press "d" for more detail and "a" for less detail. The use of "a" is not a logical choice.

22. Some of the IPB information is keyed to the paper TO. For example, the parts list refers to Figure X in the paper IPB. It would be necessary to go to the paper IPB to use it. This is not acceptable since, in a fielded system, there would be no paper IPB.

23. The typical delay between the time the NEXT key is pushed and the presentation of the next procedural frame is 10 to 12 seconds. More complex graphics take somewhat longer.

24. It would be difficult to locate information in the system if the user does not know what section of the TO it is in. The only indexing techniques used are those available in the TO. If a technician would have trouble finding the information in the TO, he would have trouble finding it in the CMAS. In fact, it probably would be harder to find information in the CMAS than in the paper TO. It is easier and quicker to page through a paper TO than to page through the CMAS (which takes 10 to 12 seconds per frame).

25. When a fault is identified, the troubleshooting procedure does not give an option to go directly to corrective maintenance instructions. It is necessary to back out of the system and go to the index to find the correct instructions. Similarly, the system does not provide direct access to parts information or other pool type information from a procedural frame.

26. Questions to be answered by the technicians are formatted poorly.

27. The CMAS Main Menu is not user-friendly. If the technician wants data from Section 1, the logical key selection would be "1"; but on the CMAS system, the user must press "a."

28. Substeps are numbered just like the callouts. For example, "(1) turn oscillator switch (32) to on." The (1) should have been replaced with a., b., c., etc.

29. Proper headings are not repeated for frames continued on a second frame.

30. There are several places where the BACK key does work. In other cases, pressing the BACK key will freeze the system.

Seven of the problems described above were corrected (although not always optimally) early in the field test period and before the start of the AFHRL evaluation. These were items 3, 6, 8, 12, 15, 26, and 30. There were insufficient time and resources to resolve the remaining problems. Many of these problems would have required extensive revision of the CMAS hardware and software or extensive rewrites of the technical data.

Preliminary Data Base Design Effort

During the initial phases of the CMAS project, emphasis was placed upon developing effective techniques for delivering and presenting technical data.

However, the investigators were aware that the problems of creating and maintaining the data base required to support a CMAS would be difficult to resolve. The magnitude of the problems became apparent during the CMAS I effort when the complexities of creating a technical data base which is technically accurate were encountered. Two problem areas were identified:

1. Data Creation. Creating technical data for the CMAS I required creating not only the technical data itself but the complex codes required to control the computer's retrieval and presentation of the data. Technical data authors were required to input the complex codes by hand with only limited help from technical data authoring software developed under the NTIPS program. The result was that the creation of the data was expensive, and the data contained many system control code errors which caused many of the technical data presentation problems encountered in the CMAS I evaluation.

2. Technical Data Presentation. The technical data and technical data presentation software developed in the CMAS system could be operated on only one computer system. When it was realized that the computer system, as configured, was inadequate to support the CMAS, it was not possible to change to a more suitable system because the software and data base could not be used with any other system. This weakness prevented transferring to another system which would have improved the chances of the CMAS I being successful. It also highlighted another consideration: the necessity of designing the data base so that it would not be limited to presentation on one system. This is essential so that when improved computer systems become available, the data can be presented on the new equipment or used in other ways without an extensive rewrite.

These observations, along with similar concerns expressed by other AFHRL personnel working in support of the ATOS program, led to a decision to establish an effort to study the data base design issue. The Rockwell contract was modified to add two additional requirements: (a) to conduct an analysis of the data base requirements, and (b) to develop a coding scheme for preparing the data which produces a "neutral" data base which could be presented on any computer with the required capabilities.

The Rockwell effort included a detailed analysis of Air Force specifications for intermediate level technical data. The analysis identified all types of technical data which must be supported by an ATDPS. The requirements for each type of data were then analyzed to identify each element of data and the attributes of each element. The attributes were then categorized to provide a listing of elements with common attributes. The categories provided the necessary source information for the development of a preliminary coding scheme.

The coding scheme was developed under subcontract by Datalogics, Inc. It was based upon the Standard Generalized Markup Language (SGML) being used with the ATOS program. SGML was selected as a starting point to ensure compatibility with ATOS. The SGML coding scheme tags each element of data (e.g., a paragraph, part number, or title) with an identifier specifying the type of information and relationships to other data elements (e.g., a paragraph may have codes specifying the chapter it belongs to, the preceding paragraph, or an illustration which must accompany the paragraph).

Once the technical information, with its corresponding codes, is developed and stored, it can be formatted for printing or for display on a computer. This can be accomplished using special purpose software designed to format the data according to the characteristics of the specified display device and predefined formatting rules. For example, if the data element is identified as a header element, the data will be presented (or printed) in the location on the display (or page) specified by the formatting rules and display (or page) characteristics. This approach will make it possible to display technical data on a variety of systems without modification to the data base. It will make it possible to print the data, if desired, or use it in other ways without modifying the data base.

The results of the analysis and coding specification have provided the starting point for an in-house effort. The objective of this effort is to extend and refine the set of identified data elements and to develop software for a system to author and present technical data using a neutral data representation on an ATDPS. This effort is described briefly in Section VI. A more detailed description is presented in Link et al. (1987).

Specification Development

The contract Statement of Work required Hughes to develop two draft specifications for use in procuring a CMAS system. The first specification was to establish the requirements for technical data to be presented on the system. The second was to provide the functional requirements for system hardware and software. The specifications were to be based upon the CMAS prototype and lessons learned in the field test.

After the field test was completed, Hughes developed two draft specifications (Hughes Aircraft Company, 1985c and 1985d). However, the specifications were considered inadequate in many areas and were not published. The primary problem with the technical data specification was that it provided only very general requirements for the technical data and did not adequately specify requirements for the content of the technical data. The main problem with the functional specification was that it was primarily a system hardware specification, rather than a functional specification. The specification of hardware requirements was beyond the scope of the effort and dependent upon many operational considerations that could not be accurately determined at the time.

Discussion and Conclusions

Although the prototype CMAS developed under this effort fell far short of the program goals, it did provide much valuable information and many "lessons learned." The effort did establish the feasibility of an automated system for presenting technical data. Technicians were able to perform representative maintenance tasks without difficulty using data presented on the CMAS. Even though the system did not receive general acceptance by the technicians, there were clear indications that they would readily accept an automated system once certain design flaws (such as response time) were corrected.

The effort provided important lessons for the further development and refinement of future automated technical data systems. It clearly reinforced AFHRL's long-held position that user acceptance is paramount for automated systems such as CMAS. The CMAS did not gain the acceptance of the technicians primarily due to its slow response time and the presence of features which made it difficult to use (not user-friendly). The criticality of user acceptance makes it essential that potential users be involved in the design of future systems. Technicians participating in the design studies had many valuable inputs which, if they had been implemented, would have greatly improved the system and acceptance by the technicians.

The results of the CMAS field test provided the basis for a number of design guidelines and recommendations for developing future systems. The results clearly supported the following recommendations for the development of future automated technical data systems:

1. The system must be user-friendly. To ensure user-friendliness, the system should provide:

a. A rapid response time. The time to retrieve a frame of procedural data should not exceed 5 seconds and preferably, should be much less.

b. An easy means for locating and accessing data.

c. A simple means of moving about in the data base (move from one section to another, retrieve support data, retrieve parts information, etc.).

d. An indicator showing the user's location in the data base.

2. Multiple levels of detail (tracks) should be provided for procedural data. The findings of the field test suggested that two tracks are adequate for application with technical data for electronic systems. However, it is unknown whether two tracks are adequate to support the maintenance of mechanical systems. Further research is needed to examine this issue.

3. The "job guide" format used in this study proved to be an effective format for presenting procedural data via an automated technical data system. When this format is used, only those callouts referenced in the text of the frame should be shown on the supporting illustration.

4. The use of a pyramiding approach to the presentation of complex diagrams, such as schematics, is recommended. The diagrams should be presented such that each drawing is of a size which is readable as first displayed.

5. The use of color-coding to identify functional segments of schematics or similar diagrams is recommended. The value of other uses of color-coding (e.g., to identify classes of components such as switches) on locator diagrams is uncertain and requires further research.

6. A resolution level of approximately 50 pixels per inch was sufficient for graphics required to support electronic systems. However, it is unknown whether this level of resolution is sufficient for graphics supporting

maintenance of mechanical systems. Graphics for mechanical systems usually are more complex and require the display of graphic elements (such as circles, splines, and diagonal lines) which are more difficult to represent on a low-resolution computer display. Research is needed to clarify this question.

7. Technical data for presentation on an automated technical data system must be 100% accurate. Thorough validation and verification of all data are essential. This is especially critical for procedural data intended for use by personnel with limited experience, since the inexperienced technician does not have the background to compensate for errors in the data. The problem of ensuring complete accuracy of the technical data is much more complex for automated technical data since, not only does the information have to be technically accurate, the branching instructions must lead to the correct next frame. The codes which tell the computer which frame to go to next, which frame to go to if the user wants to back up, etc. must be accurate. Otherwise, the user could be sent to a totally irrelevant part of the data base (never to return) and be forced to abort and start over (assuming that he realizes that an error has been made).

In retrospect, one can identify a number of reasons for the failure of the project to develop a prototype CMAS system which met the design goals. A major mistake made by both the Government and the contractors was to underestimate the complexity of the task and the resources required to accomplish it. This led to too much of the resources and time being spent on tasks of lesser importance (such as the identification of tasks for the sample data base), leaving insufficient time and funds to build the actual prototype. Technical misjudgements were made also. Perhaps the most serious was the selection of the Rastertech color graphics terminal. The effort required to make the terminal work with the MODCOMP computer and the NTIPS/Simpler software used up an excessive amount of resources and time. The "cludge" system which resulted was unable to meet response time requirements and was a major cause of its failing to achieve user acceptance.

The net result of these and similar problems was that when it came time to develop the actual prototype and technical data for the field test, there were inadequate time and resources left to do it right. As a result, many shortcuts (e.g., including all callouts on a locator graphic whether referenced in frame or not) were taken, and features known to be desirable (e.g., pyramid graphics) were not included. In addition, there were insufficient funds and time to create and validate the technical data and debug the system. The result of these and other factors (e.g., failure to apply sound human factors principles) was a system which was not usable and not acceptable to the technician.

The Hughes/Rockwell, Behavioral Technology, and Unified Industries efforts have established a solid background for the development of an effective prototype CMAS system. Immediately following the field test, an AFHRL in-house effort was established to develop a second prototype CMAS. This effort is described in the next section.

V. CMAS II DEVELOPMENT AND EVALUATION

The CMAS I (Rockwell/Hughes) effort had demonstrated the basic concepts for an automated technical data presentation system and shown that such a

system is feasible. However, it was realized that significant improvements in the system were essential before it would be acceptable to technicians and usable in an operational environment. An in-house effort was therefore established to develop and demonstrate an improved CMAS system which would not have the limitations of the CMAS I and would achieve ready acceptance by the technicians. This in-house effort developed a second prototype system known as CMAS II.

The purpose of the CMAS II effort was to develop and demonstrate an improved CMAS which: (a) did not have the limitations of the CMAS I, (b) would be well accepted by the user (technician), and (c) incorporated features which were practical for an operational system. In developing the CMAS II, emphasis was placed upon:

1. Improving response time (not to exceed 5 seconds for presentation of a procedural frame).

2. Improving the MMI to make the system easier to use, more flexible, and user-friendly.

3. Improving data access techniques to make it easier for the user to locate information and move around in the data base.

The CMAS II prototype was developed to demonstrate and test the potential of an automated technical data system. It was not intended for actual operational implementation. For the system to be suitable for operational use, additional work would be required to simplify the process of creating technical data for presentation on the system and to improve the capability of the system to store and present graphics.

The development of the CMAS II, descriptions of the hardware and software, development of the technical data, and the results of a field demonstration are discussed in the following sections.

System Description

Hardware

The hardware chosen for CMAS II was the Grid Compass II computer Model 1139 (Figure 36), with a Grid Winchester disk Model 2101. The Grid Compass II computer was selected because it had the capabilities required to support the CMAS II and was readily available. The Grid Compass II was an off-the-shelf, lap-top microcomputer that was originally designed as a general-purpose business computer. However, its small size and capability to present graphics made it an excellent choice for the CMAS II prototype. The specifications of the Grid Compass II computer and disk drive are presented in Table 5.

The Grid Compass II computer and Winchester disk were the only hardware required for the CMAS II prototype. The two units required less than 3 square feet of space on a table or workbench. The two units could be conveniently located on a workbench and leave plenty of room for the technician to work. By comparison, the Rockwell/Hughes CMAS I prototype installed at Offutt AFB used approximately 50 square feet of floor space and required a rearrangement of the Radar Shop.

Figure 36. Grid Compass Computer, Model 1139.

Table 5. CMAS II Hardware Specifications

Feature	Specification
Computer:	
Model	Grid Compass Model 1139
Memory	
Random Access Memory	512 KBytes
Bubble Memory	384 KBytes
CPU	Intel 8086
Arithmetic Coprocessor	Intel 8087
Display	Electroluminescent
Active Display Area	19.2 cm 9.6 cm (7.56 x 3.78 inches)
Resolution	512 x 256 pixels (66.6 pixels per inch)
Weight	10 pounds
Dimensions	11.5 x 15 x 2 inches
Power Source	120/220 VAC
Keyboard	Standard QWERTY
Disk Drive:	
Model	Grid Model 2101
Capacities	
Hard Disk	10 MBytes
Floppy Disk	360 KBytes
Power Source	120/220 VAC

Software

There was no off-the-shelf software available with all of the capabilities required for the CMAS II. However, a software package was available from Grid Systems which had many of the features required. This software, known as Grid DemoInterpreter, had been developed by Grid Systems to create and present "slide shows" to demonstrate the capabilities of the Grid Compass II computer. The DemoInterpreter software provided the capability to create and display a frame composed of text, graphics (bit-mapped), or a combination of text and graphics. The capability was provided to go to the next frame in a predetermined sequence by pressing a specified key or to branch to one of several frames at the user's option (by selecting from a menu). The DemoInterpreter software provided the basic capabilities to create a small data base composed of frames of information for presentation, to present the frame of data, and to move about in the data base. However, analysis of the capabilities of the DemoInterpreter software indicated that the software did not provide adequate capability to move about in the data base for our purposes. In addition, the process required to create data for presentation using the DemoInterpreter was too slow and cumbersome for use in developing the large amount of data required for the CMAS II. Also, there was concern that the DemoInterpreter software would not provide a sufficiently rapid response time.

Although the DemoInterpreter software did not meet the requirements for the CMAS II, it provided a good starting point. Extensive revisions were made to the DemoInterpreter software by AFHRL to add the capabilities required and to simplify creation of data for presentation on the system. The following capabilities were added to the DemoInterpreter software:

1. Capability to predefine windows for text and graphics.

2. Simplified procedures for inputting textual information (e.g., word wrap).

3. Simplified procedures for defining the position of text and graphics on the display.

4. Capability to go directly to a specific frame or section of the data base by inputting an identifier (e.g., frame number).

5. Capability to return directly to a starting point after branching to a different frame.

6. Simplified procedures for defining and changing fonts to be used in a window.

7. Capability to display graphics more rapidly.

8. Capability to pan or scroll graphics.

9. Capability to perform arithmetic computations on data input by the user.

With the addition of the capabilities described above, the DemoInterpreter software provided the basic capabilities desired for the CMAS II, with the

exception of the capability to rescale or zoom graphics and the capability to display a frame of procedural data in less than 5 seconds. The addition of a suitable zoom capability would have required a change in the basic approach to handling graphics (from bit-map graphics to vector graphics) and would have required an extensive software development effort. The time and resources required to develop the software to add the zoom capability were beyond the scope of the effort. Thus, the zoom capability was not provided in the CMAS II.

The requirement that a frame of procedural data be presented in less than 5 seconds was considered to be essential. This problem was solved by loading frequently used graphics into the computer memory at the beginning of the session and by developing software to "precompile" the data base into a binary form. This strategy proved to be effective. The time required to present a frame of procedural data was reduced to between 2 and 3 seconds for a typical procedural frame--well within the requirement. Although the complete presentation of a frame took between 2 and 3 seconds, the response time appeared to be much faster since the computer would actually begin painting the frame in less than .5 second.

Man/Machine Interface

The MMI was designed to provide the technician with maximum flexibility in using the system. A major consideration was to provide the user with the ability to go from one location in the data base to any other location in the data base by a simple means, requiring a limited number of keystrokes. This capability was considered essential to eliminate the "boxed-in" feeling reported by technicians participating in the CMAS I field test.

Another goal in the MMI design was to limit the number of keystrokes required for most routine operations, such as going to the next frame or responding to a "yes" or "no" question. This capability was provided by making it possible to go to the next frame by pressing "SPACE BAR," to go to the previous frame by pressing "B," or to respond to a "Yes or No" question by pressing "Y" or "N." Access to other parts of the data base such as Theory of Operation was provided through an Options Menu (Figure 37) which could be recalled by pressing "O." The optional materials could be retrieved by selecting from the menu. Cues were presented at the bottom of each frame to advise the user of the available choices.

Direct access to any part of the data base was provided by the direct access mode. The direct access mode could be entered through the Table of Contents frame or through an options menu. Using the direct access mode, the user could go directly to any frame or procedure by entering the frame number or procedure title and pressing RETURN. A direct access mode was also provided for location of parts information. By entering the part number or reference designator, the user could go directly to the frame providing detailed information on and an illustration of the desired part.

Initial entry to the data base could be achieved through the direct access mode (an option at the title frame) or through a sequence of Table of Contents frames which progressively narrowed the choices until the desired information or procedure was identified.

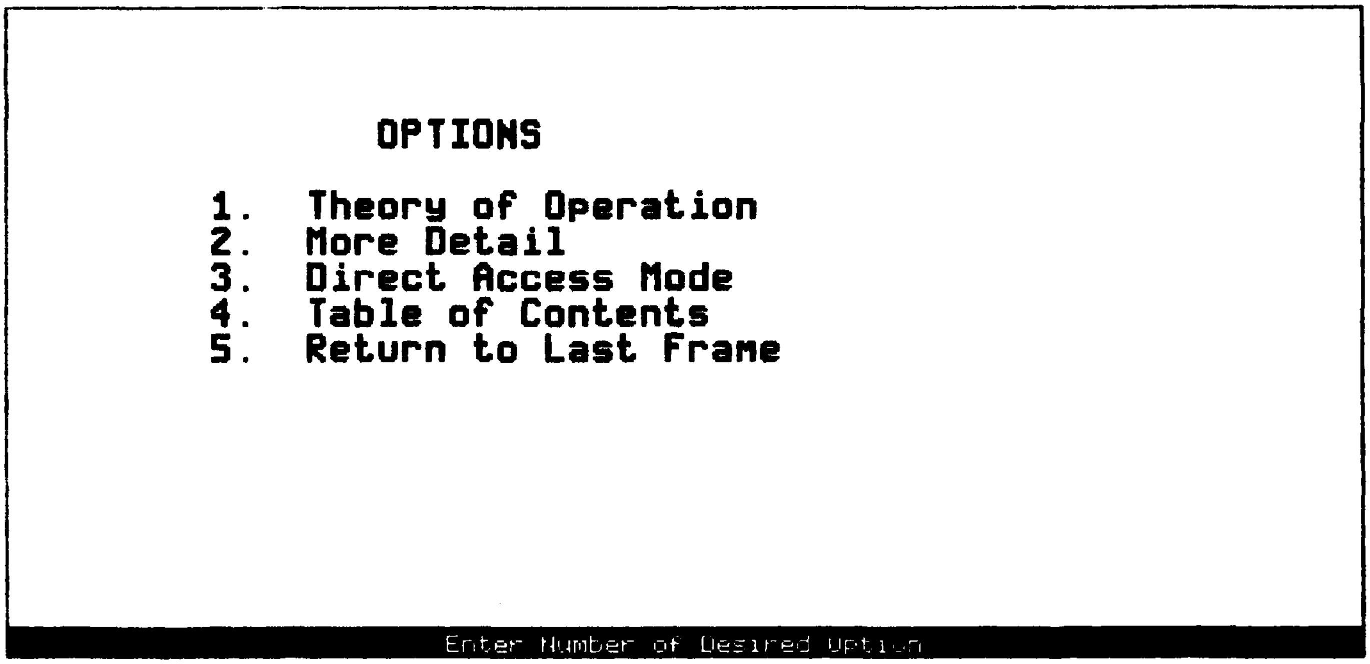


Figure 37. Example Options Menu Frame.

The diagrams presented in Figures 38 and 39 illustrate the data access capabilities provided by the system.

For graphics larger than screen size, a capability was provided to scroll or pan the graphic. When the scroll option was available, an icon composed of up/down/left/right arrows was displayed in the lower right corner of the display. When the icon was present, the user could scroll the display up, down, left, or right by using the arrow keys on the keyboard. When scrolled, the graphic gave the appearance of moving slowly across the screen. This feature was provided primarily for the presentation of schematics and other large diagrams (see Figure 40).

In some tasks, the technician is required to perform arithmetic calculations to complete a test or measurement. The CMAS II provided a feature which allowed the user to input the raw data into the computer using the keyboard. The computer would respond by asking the user to verify that the data were input correctly. When confirmed by the user, the system performed the calculations and displayed the result. If an out-of-tolerance condition was found, the computer advised the user and provided an option to go directly to the appropriate procedure for further troubleshooting or repair instructions.

One of the most time-consuming tasks that a technician is required to perform is the location of parts information. For example, if a technician is troubleshooting a fault using a TO, the TO will tell him the name or reference designator of the part that must be replaced. He must then go to the IPB to obtain the part number and other essential information. Then, if he wants to order the part, he has to go to a microfiche file to obtain the National Stock Number. The CMAS II provided a solution to this problem. When a requirement for a part was identified, the technician could select Illustrated Parts

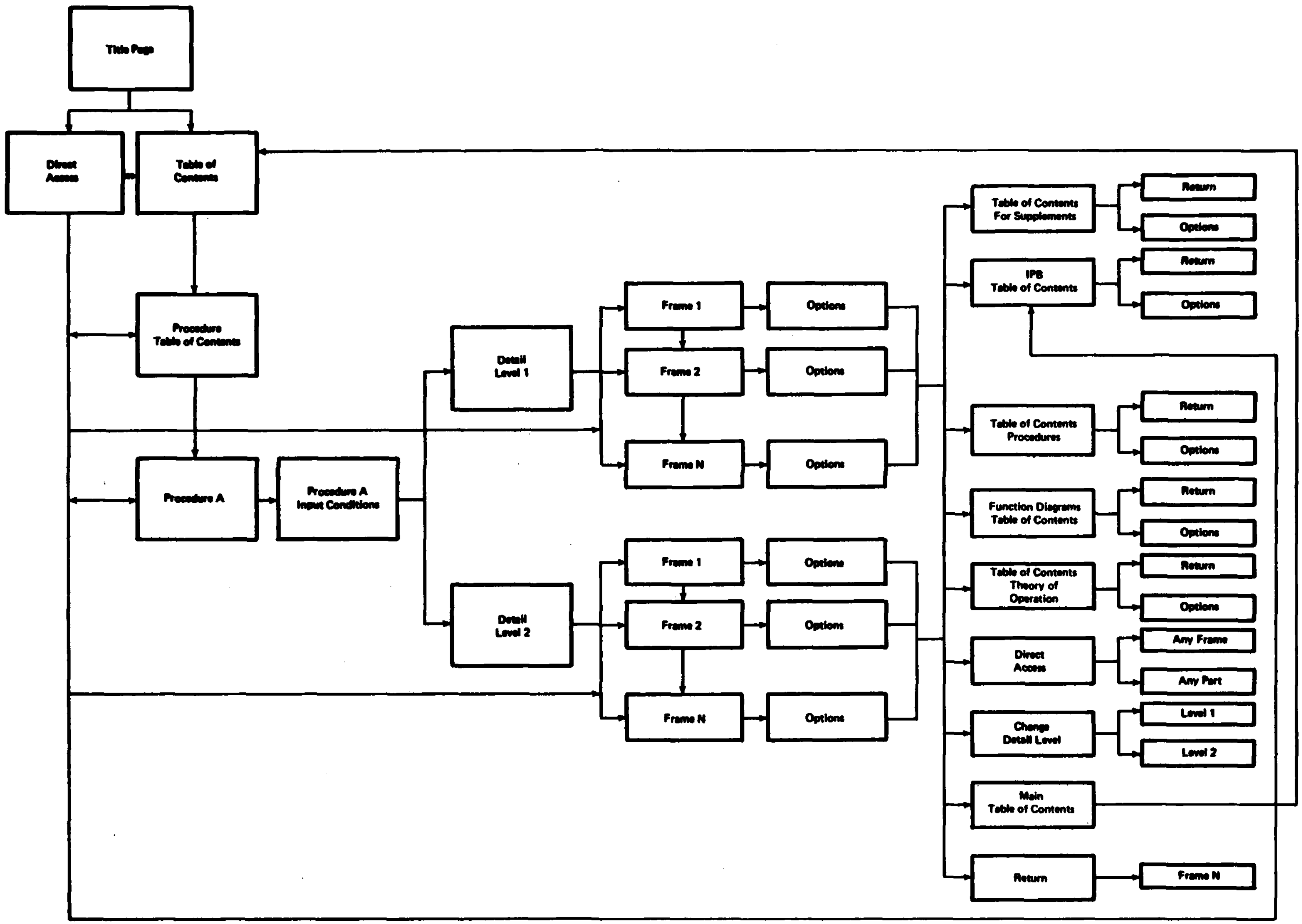


Figure 38. Flow of Information - Procedures.

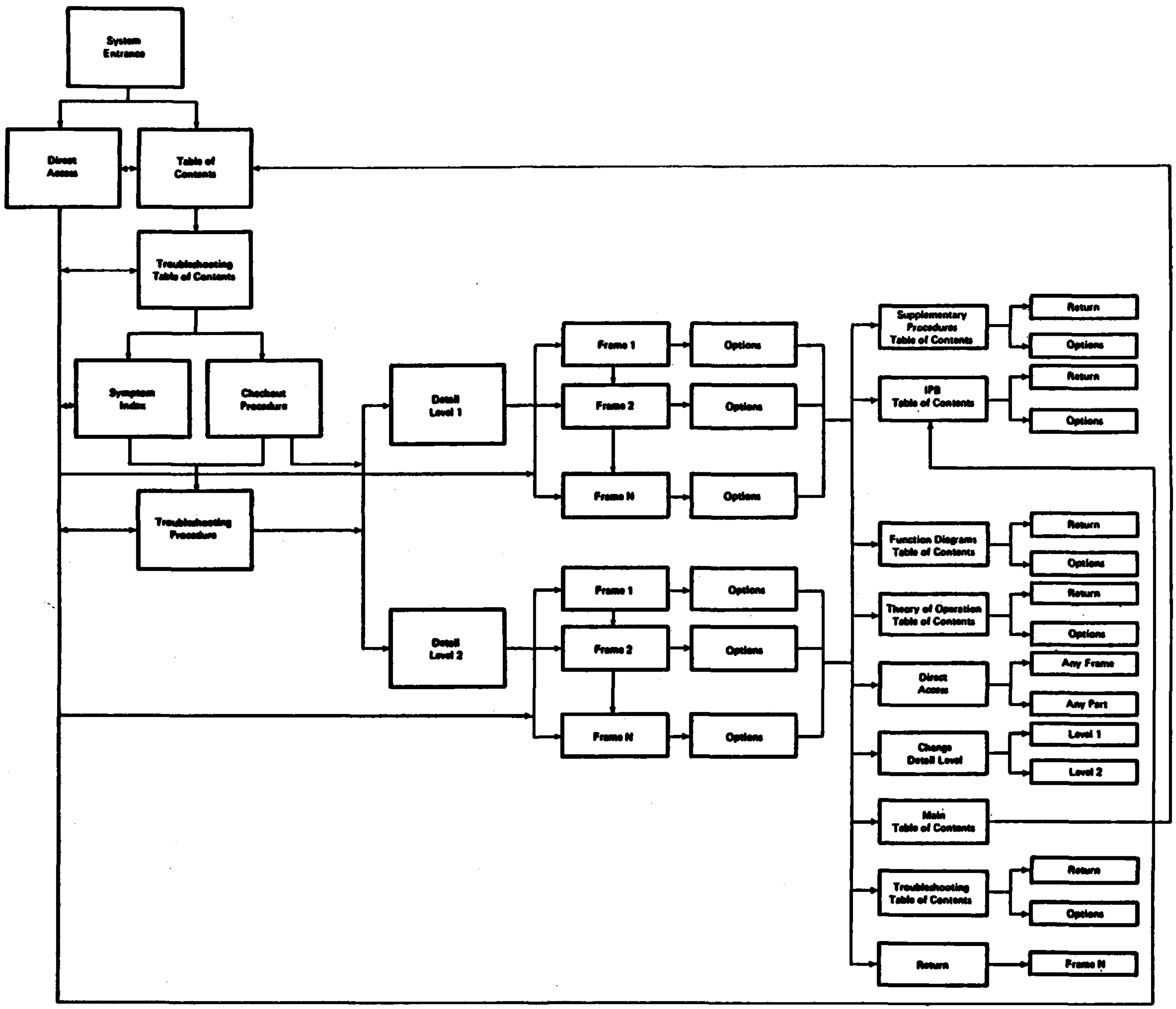


Figure 39. Flow of Information - Troubleshooting.

Information from the Options Menu. The system would respond with the necessary information on the part, including the reference designator; part number; stock number; units per assembly; source code; repair code; source, maintainability, and recoverability code; and a description (see Figure 41). The CMAS II also provided the capability to recall specific information on a part by using the direct access feature. In this case, if the technician entered the reference designator or part number, the system would respond with complete information on the part.

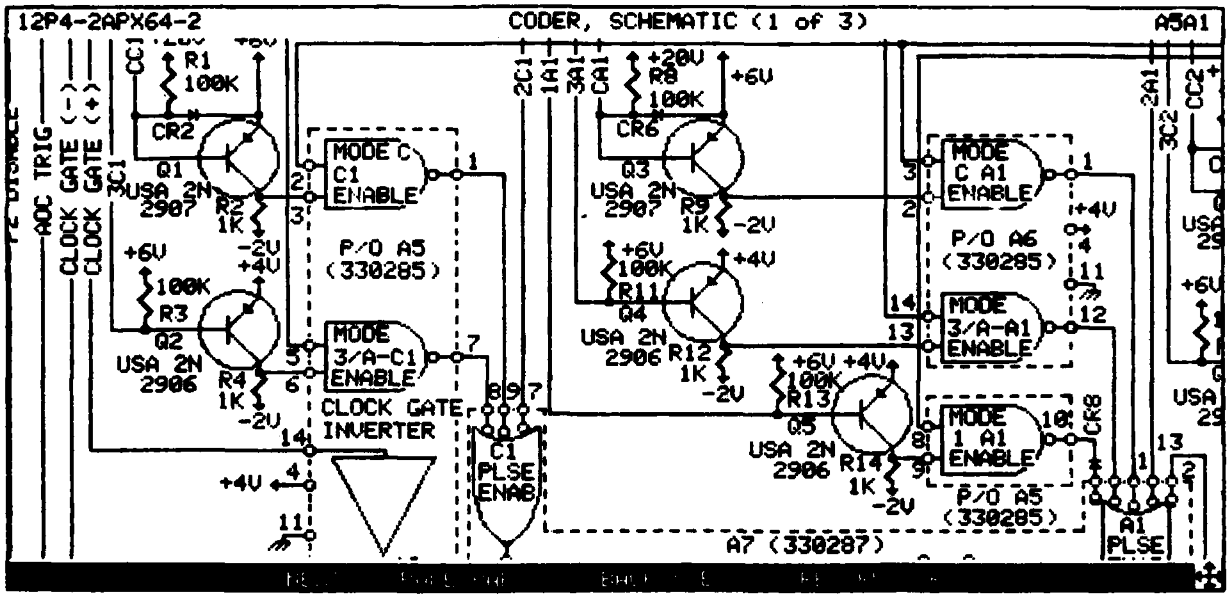


Figure 40. Example Schematic Diagram Frame.

The CMAS II demonstrated a unique approach to the identification of parts from an IPB illustration. Information on specific components of a printed circuit board could be obtained by moving an arrow displayed on the screen to the component of interest. When the arrow crossed the boundaries of the component, the component was highlighted. The user could then retrieve information on the component by pressing the return key (see Figure 42).

The CMAS II provided many opportunities to branch or otherwise move to a different part of the data base. In some cases, the user might want to return to his point of departure from the procedure he was using (e.g., go to theory of operation and return to the step being performed). The CMAS II permitted the user to return to the appropriate point by pressing "R."

Data Presentation Formats

Formats were developed for the presentation of procedural technical data in two levels of detail (Track 1 - less detail, Track 2 - more detail).[3]

[3]Attempts to prepare data in three tracks indicated that a third track (more detailed) is not practical for use with this type of equipment (electronic). Three tracks may be appropriate for other types of equipment.

Formats provided for support information were in only one level of detail. All formats used a 7 x 9 pixel character to present technical information, and a 5 x 7 pixel font to present reference information (TO number, etc). All formats reserved the top portion of the screen to display the TO number, section title, and frame number to provide location information. The bottom of the screen displayed the options available from that frame. The basic formats used for CMAS II are described below.

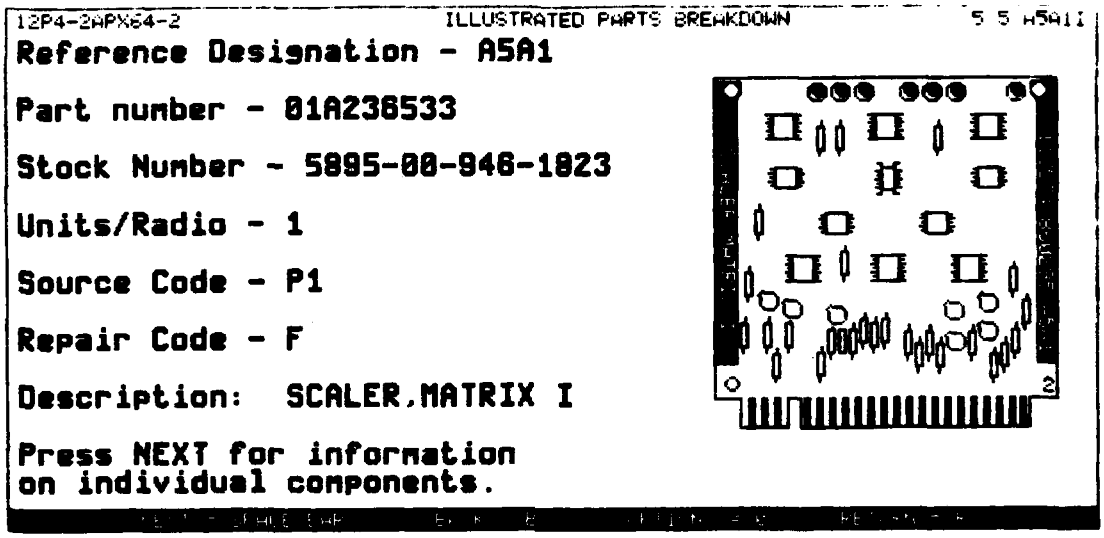


Figure 41. Example Parts Information Frame.

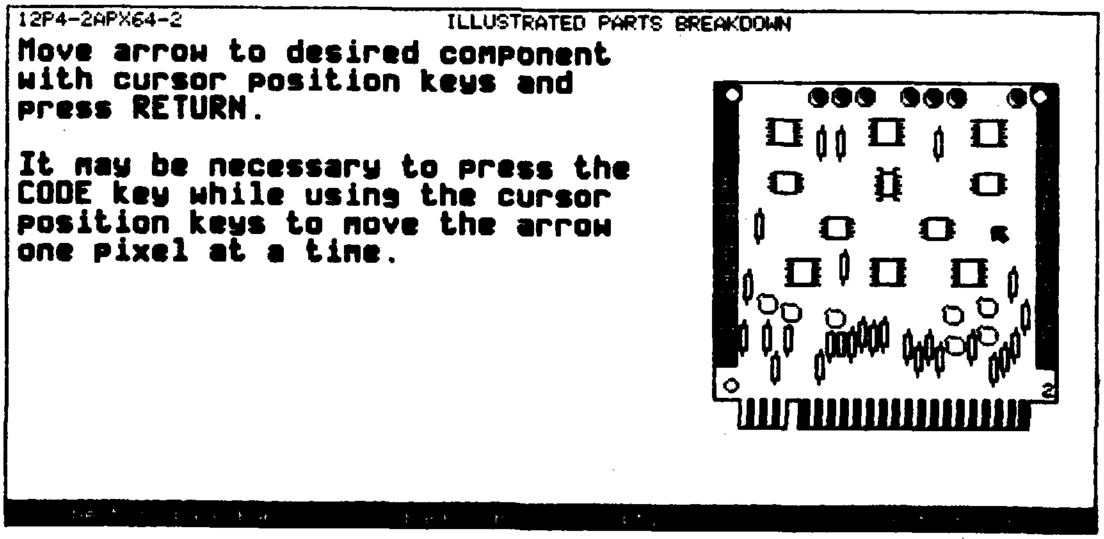


Figure 42. Example Parts Selection by Graphics Menu Frame.

Procedural Data Formats. The formats developed for procedural data were based upon the Job Guide concept and were similar to those proposed by Hatterick (1985) and those used for the CMAS I effort. However, in addition

to differences in display size and shape, the CMAS II differed from the CMAS I formats in the following ways:

1. Presented the TO number, procedure title, and frame number at the top of the frame. This information helped the user maintain his orientation in the data base and provided reference information for later use with the direct access mode.

2. Provided only those callouts on a graphic that were actually referenced in the frame. This eliminated the need for the user to search through numerous unused callouts to locate the referenced callout.

The procedural formats provided step-by-step instructions supported as appropriate by locator illustrations showing the locations of the referenced components or graphics presenting test information (such as illustrations showing expected waveforms on an oscilloscope display). Callouts were used to key the procedure to the illustration. In most cases, the technical data portion of the display was divided into three windows, as shown in Figure 43. The windows were used in three basic layouts to present the data:

1. Textual information on the left (window one); illustrations in windows two and three.

2. Textual information in windows one and three; an illustration in window two.

3. Textual information in all three windows.

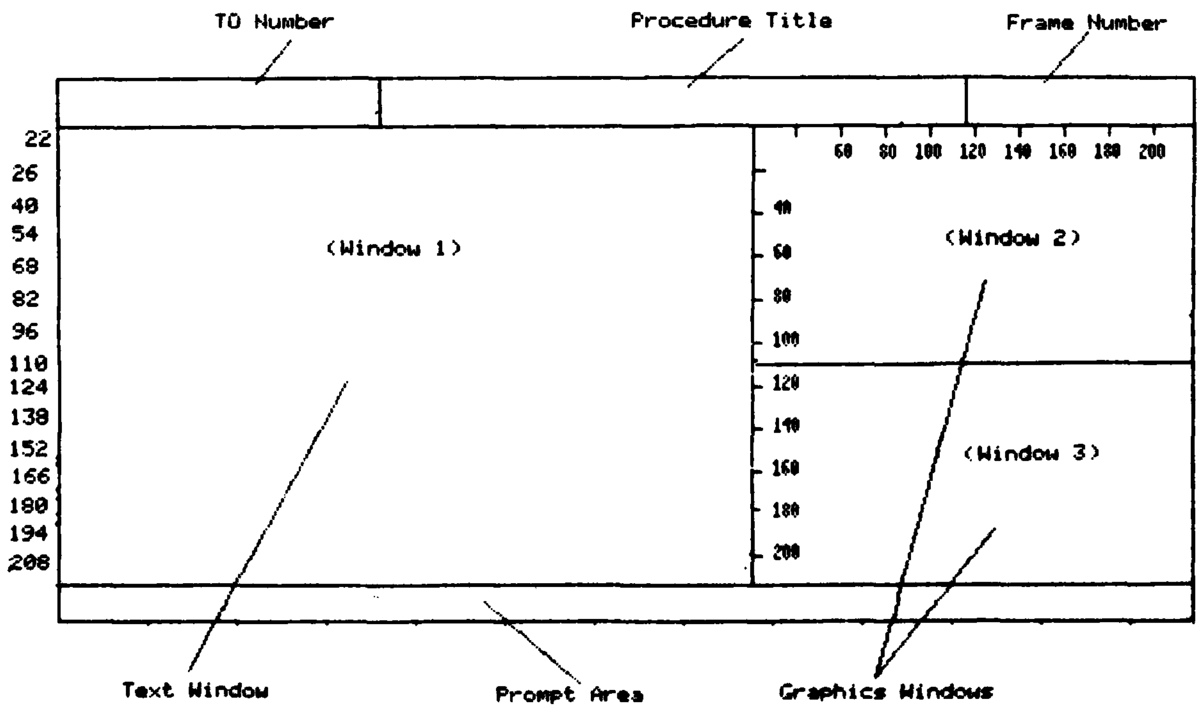


Figure 43. Window Layout for a Typical Frame.

Other text or graphics windows could be defined by the author. The above arrangement was used whenever practical to maintain consistency in the presentation of the data and to simplify creation of the data.

Special cases existed which required the above layouts to be modified. One case was the handling of warnings, cautions, and notes. Warnings, cautions, and notes were displayed one at a time, centered vertically and horizontally on the screen with the word "WARNING," "CAUTION," or "NOTE" highlighted above the text. This was done to ensure that warnings, cautions, and notes were not skipped over. Another special case was when a graphic was too large to fit into the specified window. There were several options available to solve this problem. The first was to scroll the graphic, using the cursor control keys. For extremely large drawings, such as schematics, the entire screen was used except for the top and bottom information sections. When scrolling was offered as an option, an icon consisting of four arrows pointing up, down, left and right was displayed in the lower right-hand corner of the screen. Another special case was when the drawing was long and narrow. In this case, the drawing was displayed on the bottom portion of the screen, with text placed above the drawing.

As indicated earlier, the procedural data were presented in two tracks. The formats were similar for the two tracks. The primary difference was that the Track 2 frames were always supported by locator illustrations. Track 1 frames usually did not include locator illustrations. Examples of Track 1 and Track 2 procedural frames are shown in Figures 44 and 45.

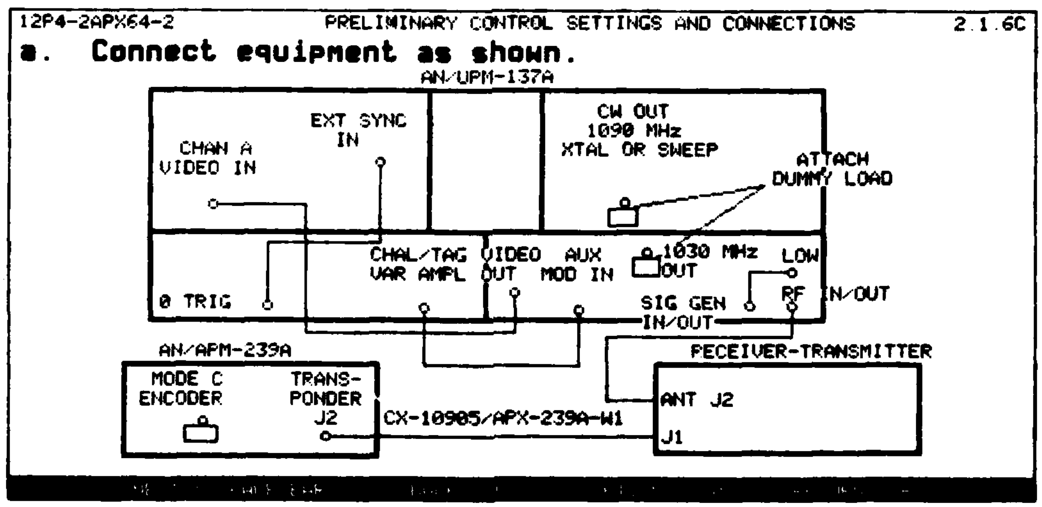


Figure 44. Example Track 1 Frame.

The text in each frame consisted of the maximum number of steps that could be legibly included in the screen with the associated graphics. All steps were labeled alphabetically within each complete procedure (e.g., RECEIVER SENSITIVITY CHECK). Individual steps were single-spaced, with double-spacing between steps to make it easier for the user to keep his place and not skip steps. In many cases, the graphics determined the number of steps displayed

on a screen. If two consecutive steps required the same graphics, the steps were displayed together. However, if they required different graphics and there was not enough room for all required graphics in the frame, the steps were presented separately.

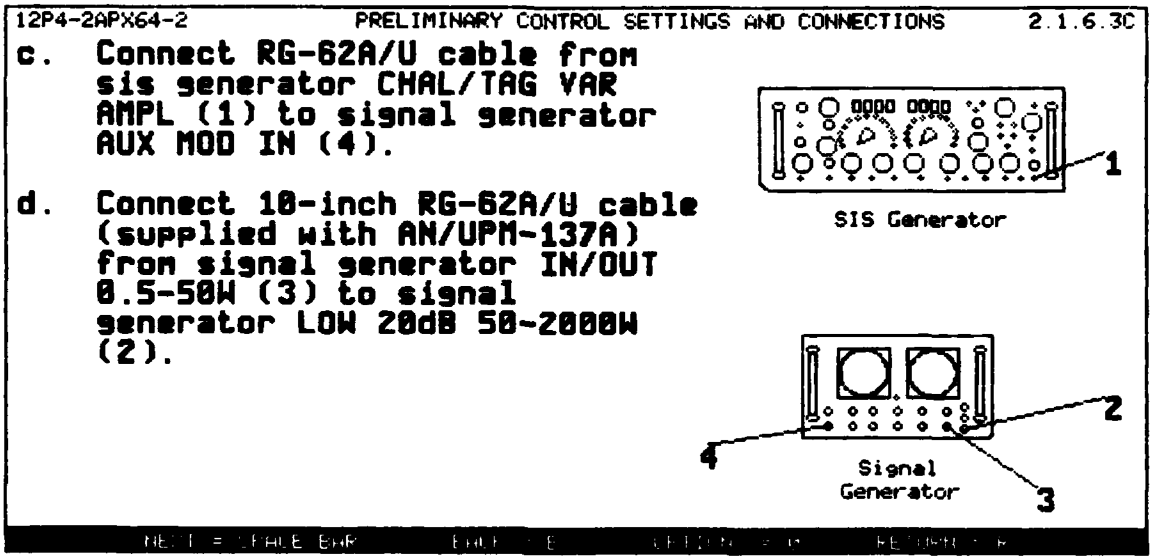


Figure 45. Example Track 2 Frame.

Input Conditions frame(s) were provided at the beginning of each procedure. Input Conditions frame(s) provided the technician with information needed to prepare for the job (see Figure 46). The following information was provided for each task:

Applicable Serial Numbers
Personnel Required (number and type)
Parts Required
Supplies
Special Tools and Test Equipment
Warnings, Cautions, and Notes applicable to the task

Table of Contents. The Table of Contents was displayed in a menu format. The title appeared at the top, with the choices listed below. Each choice was numbered. Selections were made by entering the number of the desired choice (see Figure 47).

Schematic Diagrams. A full-screen format was used to present schematics and other larger-than-screen-size diagrams (see Figure 40). As for other types of data, the TO number, schematic title, and frame number were displayed at the top of the frame. User option information was presented at the bottom of the frame. An icon (left/right/up/down) was displayed in the lower right corner to tell the user that the graphic was larger than the screen and could be scrolled. Although the CMAS II test did not include other types of diagrams (such as hydraulic diagrams), the same format could be used for those diagrams.

12P4-2APX64-2 CHECKOUT AND ANALYSIS 2.1.1.1C

INPUT CONDITIONS

Applicable Serial Nos: All

Supplies: None

Personnel Required: One

Special Tools and Test Equipment:
AN/UPM-137A Radar Test Set
AN/APM-239A Transponder Test Set
AN/APM-245 Mode 4, Signal Generator Simulator
Fault Isolation Meter

Figure 46. Example Input Conditions Frame.

12P4-2APX64-2 TABLE OF CONTENTS

1. THEORY OF OPERATION
2. CHECKOUT AND ANALYSIS
3. DIRECT ACCESS MODE
4. ILLUSTRATED PARTS BREAKDOWN
5. TROUBLESHOOTING PROCEDURES
6. SCHEMATIC DIAGRAMS

Figure 47. Example Table of Contents Frame.

Theory of Operation. Formats for presentation of theory of operation information varied with the type of information presented. If the data were text only, the information was presented in one column, single-spaced, in one large text window. If a graphic was required, a portion of the frame was reserved for the graphic (see Figure 48).

CMAS II Evaluation

The CMAS II was evaluated by developing technical data for a testbed system, inputting the data to the Grid Compass II computer, and taking it to an operational unit for a field demonstration. There it was used by Air Force technicians to perform maintenance on the testbed system.

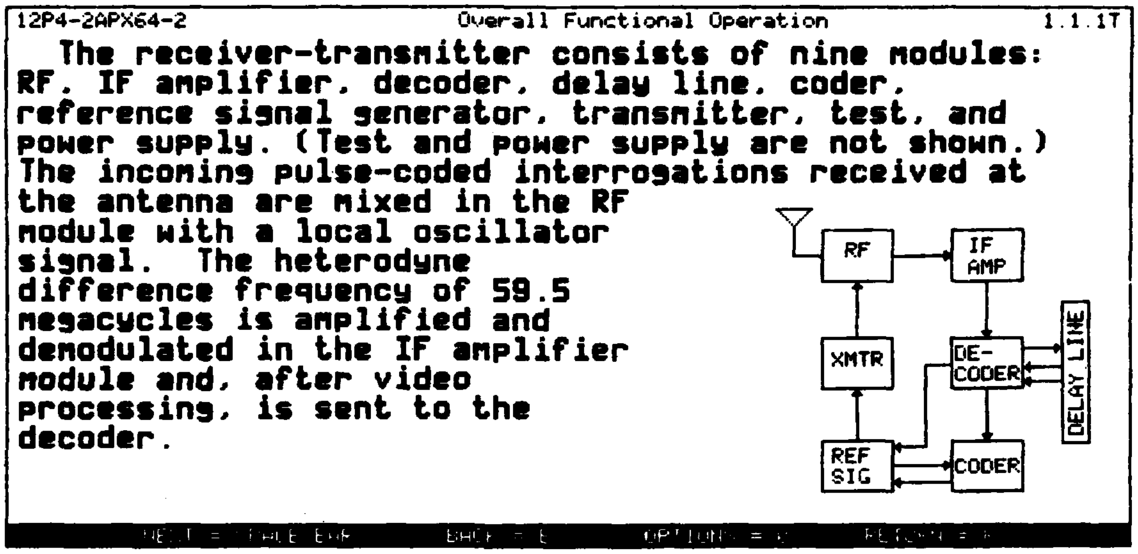


Figure 48. Example Theory of Operation Frame.

Test Data Development

The RT-728A transponder from the AN/APX-64 Identify Friend/Foe (IFF) transponder was chosen as the testbed for use in evaluating the CMAS II. The RT-728A was also used in the CMAS I evaluation. The transponder is used in the B-52, KC-135, T-38, and many other aircraft. It is also used by the Navy and Marines in some helicopters. The transponder was chosen because of the availability of a functional RT unit and adequate technical information on the system. Also, subject-matter experts on the equipment and a suitable test site were readily available.

Available resources and time constraints did not permit the development of a complete set of automated technical data for the RT-728A. A sufficient sample of maintenance data and support information was developed to permit an evaluation of the system. Graphics were provided as necessary to support the maintenance procedures, theory of operation, and IPB information. The following data were developed:

1. Maintenance Procedures:

a. Minimum Performance and Checkout and Analysis procedures for the RT Unit (Section 6 of the TO).

b. Troubleshooting procedures for the RT Unit (troubleshoot to the module).

c. Troubleshooting procedures for the IF Module (limited to identification of faults on one printed circuit board).

2. Support Data:

a. Theory of Operation.

b. Illustrated Parts Breakdown (limited to basic unit and IF module).

c. Schematic Diagrams (IF module printed circuit boards only).

The original TO data were written in a narrative style with limited use of graphics. Much of the data needed was located in different sections of the TO and required the technician to search for these data. Thus, to meet the CMAS goal of providing the technician with all needed information in one place, it was necessary to restructure the data. This required a reanalysis of the data to gather the necessary information and to provide links between related portions of the data so that relevant information could be rapidly retrieved. The data from the TO were completely rewritten to fit the CMAS II formats. Where necessary, additional information was created and added. All other information in the data base that could reasonably be expected to be required at that point was identified and included with branching parameters for each frame of procedural data.

The TO provided very little troubleshooting information. Thus, once a fault was identified during the checkout procedure, the technician was expected to use system operation information, theory of operation information, schematic diagrams, etc., and his experience, to develop his own troubleshooting strategy to troubleshoot the problem. Since the TO contained only limited troubleshooting information, it was necessary to create troubleshooting procedures for use in CMAS II. Assistance in developing the troubleshooting procedures was obtained from an experienced technician at Offutt AFB. Since available resources were limited, it was possible to develop only a limited amount of troubleshooting data. Data were developed to troubleshoot the IF module to isolate a faulty circuit board in the module and to isolate a fault on one of the boards (the A5A1 board).

Story boards were created from the original TO by several in-house personnel. An example story board is shown in Figure 49. Each form represented one "frame" on the automated system. Previous and next frames, possible branching requirements, graphics needed, and callout locations for the graphics were included on each story board. The story boards were then transformed into the DemoInterpreter machine-executable code by an in-house analyst. Once complete, all data frames were reviewed for standardization and technical accuracy. These data were then taken to Offutt AFB for validation by maintenance technicians with experience in maintaining the RT-728A.

Field Demonstration

When data development and validation were completed, the CMAS II was taken to Grissom AFB for a 2-week field demonstration. The data base for the CMAS II was too small to permit a full-scale evaluation of the system. Thus, the goals of the field demonstration were somewhat limited. The objectives of the CMAS II field demonstration were to:

1. Demonstrate the use of an automated technical data presentation system in an operational environment.

2. Evaluate the usability of the system (including MMI techniques, data access techniques, and data formats).

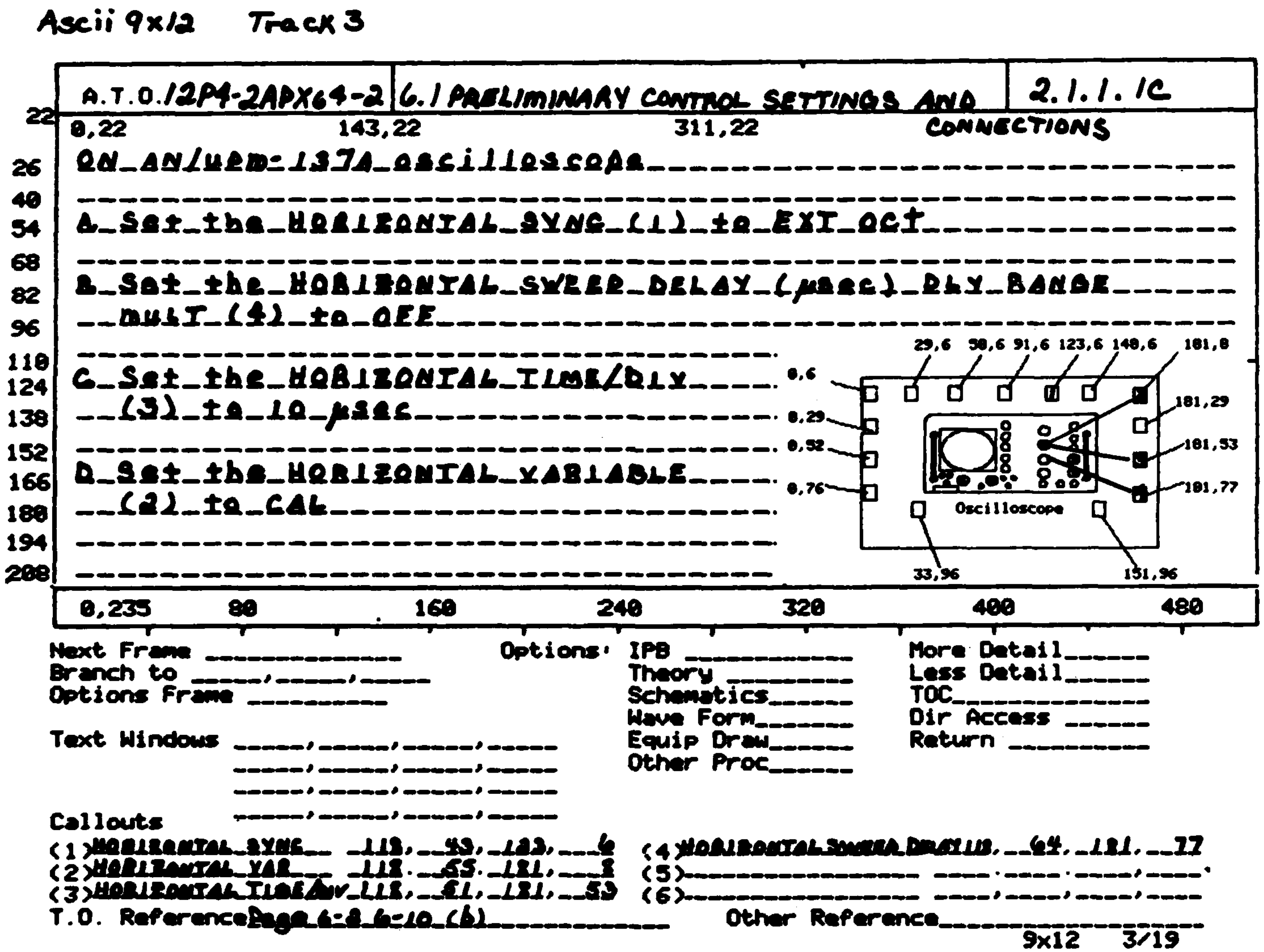


Figure 49. Example Story Board.

3. Determine the overall acceptance of the system by technicians and identify features which contributed positively and negatively to user acceptance.

4. Develop preliminary indications of the effectiveness of the system as a data presentation system in comparison to the existing paper-based system.

5. Identify methods to improve the system.

Field Demonstration Procedures. CMAS II was placed in an intermediate level shop (Radar) at Grissom AFB for a 2-week period in August 1985. The radar shop had the responsibility for maintaining the AN/APX-64 and had personnel assigned who had a wide range of experience in maintaining the system. The demonstration was conducted on a noninterference with normal shop operations basis. In some instances, it was necessary for some technicians to interrupt their participation in the field demonstration to perform mission essential tasks. The short time period and the noninterference policy limited the number and experience levels of the technicians participating in the demonstration. Other limiting factors were the small amount of data in the system and the number of planted "faults" which could be placed in the receiver-transmitter unit.

Eight technicians from the Radar Shop served as subjects for the study. Their experience in maintaining the AN/APX-64 ranged from 6 months to 12 years. Half of the subjects had more than 1 year of experience in maintaining the system, and half had less than 1 year of experience on the system. The subjects included a quality assurance inspector and a Field Training Detachment instructor (who was currently teaching maintenance of the system). In addition, one technician from the Inertial Navigation Shop was tested. This individual had no training or experience on the system. He was included to provide an indication of the ability of the system and the reformatted data to support performance by very inexperienced personnel.

Each technician was given 5 minutes of instruction on the use of CMAS II and given a set of written instructions (Appendix A) on how to use the system. At the end of this session, each technician completed an exercise to demonstrate his ability to use the CMAS II.

After the technicians were trained to use the CMAS II, they were asked to perform three tasks on the RT unit: two checkout tasks and one troubleshooting task. The two checkout tasks were judged to be equal in difficulty. Both checkout tasks required setting up the test equipment and performing the checkout procedure until an out-of-tolerance condition (sensitivity adjustment) was identified. When the out-of-tolerance condition was identified, the technician was instructed to adjust the sensitivity until it was within tolerance. One checkout task was performed using the CMAS II, and one was performed using the TO. The order of presentation was counterbalanced so that half of the subjects performed the first task using the CMAS II, and half used the TO for the first task.

The troubleshooting task required identifying an out-of-tolerance condition and then troubleshooting the system to identify the faulty module and the faulty component within the module (to the piece-part level). The fault for this task was inserted in a printed circuit board by damaging the

card to interrupt the signal flow. The damage was detectable only upon careful observation. For the troubleshooting task, the technician was started at a point further into the checkout procedure and instructed to perform the checkout until an out-of-tolerance condition was found and then isolate the cause of the problem. Although technicians in the intermediate level shop were normally authorized to troubleshoot to the card level only, they were instructed to isolate the problem to the piece part. Isolation to the piece-part level was included to further test the limits of the system to support troubleshooting. The troubleshooting task was performed using the CMAS II.

The performance of the technicians was evaluated by an observer who recorded whether the problem was successfully completed, the time to complete, errors made, and any problems encountered. After the performance tests were completed, the technicians performed a series of exercises designed to evaluate whether the technique used to present schematic diagrams was adequate. The exercises consisted of having the technician locate specific components on the diagram, follow signal flows on the schematic, and identify sources of inputs and outputs.

Following the performance tests and schematics exercises, each subject completed a questionnaire and was interviewed to determine what he liked and disliked about the system and to solicit recommendations for improvement.

Field Demonstration Results. The times required for the technicians to complete each performance test are shown in Table 6. As illustrated in the table, all of the technicians were able to satisfactorily complete all of the tests. Comparison of the data for performance using the TO and CMAS II for the checkout procedures reveals that the times were essentially the same for both conditions. No comparison is possible for troubleshooting since the TO condition was not tested. The performance times should be viewed as general indicators of performance times. There were enough interferences and extenuating circumstances in the data collection process that the data cannot be considered sufficiently clean for a formal statistical analysis.

The questionnaires administered and interviews conducted after the completion of the performance test yielded many very positive comments and only a few negative comments. The most valuable information was obtained from the interviews. The interview comments are summarized in Appendix B.

In general, the technicians were very receptive to the system. All eight technicians who completed the questionnaire indicated that they preferred to use the computer over the paper TO. Most expressed a desire to see a similar system implemented for Air Force-wide use. Several expressed disappointment at the realization that it will be several years before such a system can be implemented for widespread use throughout the Air Force. Positive reactions expressed included the following observations:

1. The computer response time was considered to be very good by the technicians.

2. With one exception, the graphics were considered to be at least as good as the graphics provided in the TO.

3. The system was considered to be very easy to use.

4. The procedures provided for locating and accessing data were considered to be effective. The direct access capability was seen as a desirable feature.

5. The presentation of IPB information was considered to be a valuable feature. The IPB information presentation capability was seen as a time saver.

6. The computer forced the technician to read every step. This made it difficult to miss a step. Thus, they felt that the use of the computer lessened the chance of making a mistake.

7. The troubleshooting capability of the system was seen as a valuable tool.

Table 6. Task Performance Times for CMAS II Field Test (In Minutes)

Subject	CO/CMAS II	CO/TO	TS/CMAS
H-1	52	28	53
H-2	32	22	17
H-3	23	25	23
H-4	30	33	26
Total	137	108	119
Mean	27.00	34.25	29.75
L-1	34	43	no
L-2	52	58	44
L-3	65	77	266
L-4	31	34	33
Total	182	212	343
Mean	53	45.50	114.33
Grand total	319	320	462
Grand mean	40.00	39.88	65.99

The primary criticism of the system expressed by the technicians concerned the presentation of schematics. Although they could use the schematics as presented on the system, several felt handicapped by the fact that they could not see the whole diagram at one time. Some also noted a problem in locating information along the edges of the schematic. Other concerns expressed by the technicians included the following:

1. It was noted that when the direct access mode was used, critical Warnings, Cautions, and Notes could be bypassed. It was suggested that the direct access technique be modified to always present the relevant Warnings, Cautions, and Notes before presenting the procedural information.

2. One technician (the Quality Assurance Inspector) questioned the two-track concept. He was concerned that the experienced technician may not know the procedure as well as he thinks, and may miss a critical step or cue.

Surprisingly, the technicians had very few suggestions for improving the system. Suggestions made which should be considered for the development of an operational system included:

1. Put the computer on a cart similar to those used for oscilloscopes. This would provide more flexibility and eliminate the risk of knocking the computer off of the workbench. It would also make more work space available on the bench.

2. Use a larger display. This would make it easier to present schematics.

3. Link related schematics together so that the computer goes directly to the next schematic when the edge of the schematic is reached.

4. Modify the direct access feature to present any relevant Warnings, Cautions, and Notes before any procedural information is presented.

Specification Development

Following the successful demonstration of the CMAS II, draft military specifications for the content and format of automated technical data were developed under contract by Applied Science Associates, Inc. (Evans 1986a). The specification provides requirements for the content of the data, requirements for writing the data, requirements for formatting the data, and requirements for establishing interactions (branching, etc.) for the data. Format and presentation requirements are based primarily upon the CMAS II and describe a very similar system. The technical content requirements of the specifications are based primarily on earlier AFHRL job performance aids research (Joyce et al., 1973).

In addition to the draft content specification, a draft specification was developed establishing system requirements for an automated technical data system (Evans, 1986b). The specification provides system requirements such as screen resolution and system response times.

CMAS II Refinement

One of the goals of the field demonstration was to identify ways of making the system better. One refinement was identified which could be readily incorporated into the system. It was suggested that the retrieval of optional information could be simplified by using a function key approach rather than the options menu approach. With the function key approach, the options would be identified on the bottom of the screen and keyed to a corresponding

function key. The desired option could then be selected by pressing the corresponding function key. This approach would allow the technician to select optional information or another mode of operation (direct access) with one key press, rather than the two or more key presses required for the options menu approach.

Since the Grid Compass II does not provide dedicated function keys, it was necessary to simulate the use of function keys. This was accomplished by designating the numeric keys as function keys. The display formats were then modified to provide a listing of available options across the bottom of each frame. Each option was identified by a number. The user could make a selection by pressing the appropriate numeric key. Figure 50 presents an example of the revised format for procedural data.

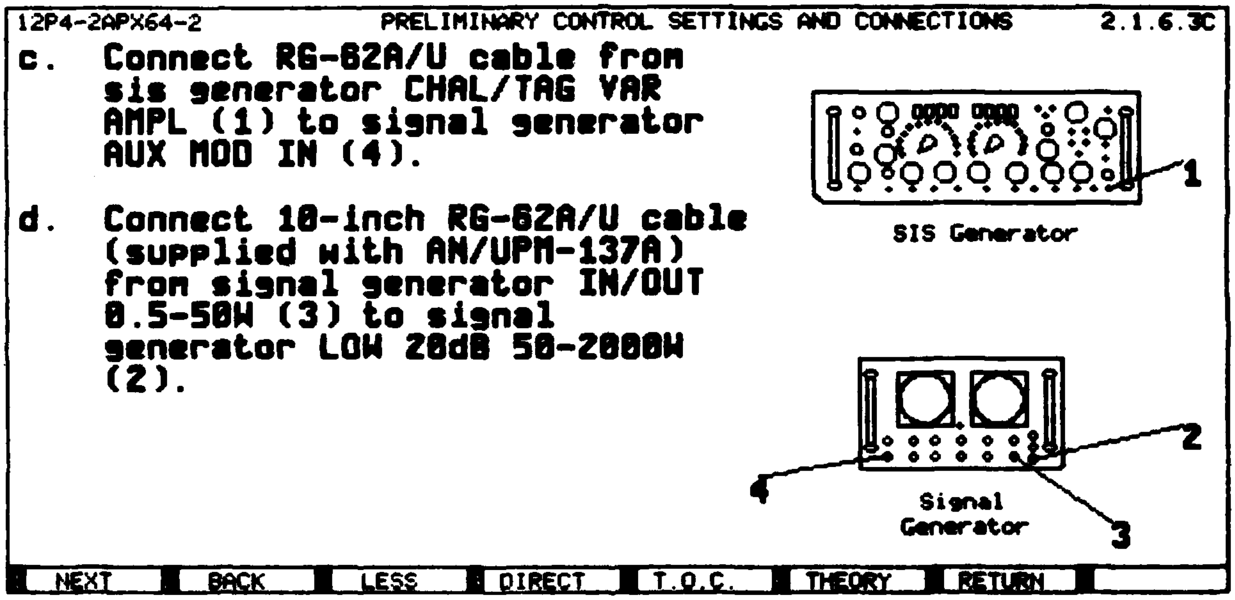


Figure 50. Example Upgraded Format for Procedural Frame.

Other suggestions were made for improving the system. These suggestions primarily involved ways to make the schematic diagrams more usable. However, the time and costs to implement the suggested approaches were greater than the resources available. Also, in some cases, the hardware and software requirements were beyond the capabilities of the Grid Compass II.

Air Force/Navy Evaluation

The Navy Personnel Research and Development Center (NPRDC) also has a program to study methods for automating technical data for maintenance. Since the NPRDC program is concerned with many of the same problems and research concerns as the AFHRL program, close coordination is maintained with NPRDC

personnel. When NPRDC personnel visited the CMAS II field demonstration at Grissom AFB to observe, it was noted that the Navy also has aircraft which use the AN/APX-64. Subsequent discussions led to an agreement for NPRDC to conduct an independent study to further evaluate the CMAS II. It was agreed that NPRDC would have full responsibility for conducting the study and that AFHRL would provide the CMAS II hardware, software, data base, and technical assistance for the effort. The results of the NPRDC study are reported in Nugent, Sander, Johnson, and Smillie (1987). The following materials were adapted from that report.

Objective

The objective of the NPRDC study (Nugent et al., 1987) was to "...extend the results of an earlier Air Force study and compare the troubleshooting performance of military technicians who obtained information from conventional, paper-based maintenance manuals and from electronic devices" (p. 1).

Approach

The experimental approach was designed to test the following hypotheses:

1. Troubleshooting will take less time when using the electronic presentation system than using technical manuals.

2. Fewer tests will be performed using the electronic presentation system than using technical manuals.

3. Fewer unnecessary replacements (modules and circuit cards) will be made using the electronic presentation system than using technical manuals.

4. More faults will be isolated successfully using the electronic presentation system than using technical manuals.

5. Inexperienced technicians using the electronic presentation system will troubleshoot as well as experienced technicians using technical manuals.

6. When using the paper-based technical manual, experienced technicians will troubleshoot better than inexperienced technicians.

7. Performance differences between the two presentation methods will be greater for inexperienced than for experienced technicians.

The basic approach adopted for the study was to use the same testbed system (RT-728A Receiver-Transmitter of the AN/APX-64, Identify Friend or Foe System) used in the AFHRL demonstration. The data base was expanded to provide sufficient data to support troubleshooting a larger sample of faults. Four separate RT-728A failures were used as troubleshooting problems for the effort. One of the faults was the same as that used in the AFHRL study. Precautions were taken to ensure that the faults could not be identified by visual inspection alone and that they provided consistent symptom patterns. Care was also taken to ensure that both the paper manual and the automated system provided sufficient information to isolate the faults. Additions to

the data base included additional schematic diagrams, illustrated parts breakdown information, and troubleshooting procedures to cover the four problems.

Thirty-six Navy, Marine, and Air Force avionics technicians from four California military installations served as subjects for the study. The technicians (12 from each service) were classified into two groups: experienced and inexperienced. Group assignments were based upon relevant field experience (1 or more years for the experienced group and less than 1 year for the inexperienced group) and judgments of the technicians' capabilities by the immediate supervisor. All subjects were volunteers. Procedures were implemented to ensure subjects' anonymity.

The subjects were tested individually at a standard AN/APX-64 workbench. They were given an orientation to the testing procedures and assigned to one of six predetermined sequence orders which counterbalanced the presentation of the troubleshooting problems and information delivery device. They were then given instruction on the use of the CMAS II and provided an opportunity to practice using it.

Each troubleshooting problem was initiated by giving the technician a description of the symptom associated with the failure inserted in the RT unit. The subject was given a specific start point in the TO or computer data base from which he was to initiate the troubleshooting. He was instructed that the only information the experimenter would provide was the time available for the test, whether a recommended replacement of a module or circuit card would correct the failure, or how to resolve difficulties encountered in using the CMAS II. A 1-hour time limit was allowed for isolating the fault to the printed circuit card. If this criterion was met, an additional 15 minutes were allowed to isolate to the component level; otherwise, the test was terminated. The test was terminated if the fault had not been isolated prior to the expiration of the time limit. Performance was observed by a trained observer who recorded start/stop times, options used in the data base, the troubleshooting path followed, and any other meaningful observations.

Following the testing session, the purpose of the study and each subject's performance on the problems was reviewed with each subject. The subjects were also asked to complete questionnaires, and structured interviews were conducted.

Results

A 2 x 2 multiple analysis of variance (MANOVA) design was used to analyze the results.

Nine of the 36 subjects were unable to isolate the fault on one or both problems performed using the technical manual. Thus, data were not available for all subjects on the Total Time to Solution and Total Tests Performed measures. As a result, two separate analyses were made: one analysis using data for all 36 subjects but omitting the time and tests-used variables, and one analysis using data for 27 subjects for all variables.

Performance Test Results. The results for the overall sample (N = 36) are shown in Table 7. As may be seen from the overall means (for experienced and inexperienced combined), time to repair and false replacements were significantly lower ($p < .01$) when the technicians used the computer than when they used the paper technical manual. In addition, significantly more problems were successfully solved ($p < .01$) when the computer was used than when the paper manual was used. The table also indicates that significantly fewer test points were checked using the paper manual than using the computer.

Table 7. Performance Differences Resulting from the Use of Technical Manuals Versus the Use of the Electronic Presentation System for the Overall Sample (N = 36)[a]

Measure	Mean Technical Manual	Mean Computer	F(1,68)	p
Time to faulted card (min)	56.5	24.4	35.72	.01
Test points checked	3.6	5.6	12.90	.01
False replacements	1.2	0.0	25.96	.01
Problems solved	1.7	2.0	9.90	.01

[a]From Nugent et al., 1987, p. 8.

Similar results were obtained when the data were analyzed for the restricted sample (N = 27). The results of this analysis are presented in Table 8.

Table 8. Performance Differences Resulting from the Use of Technical Manuals Versus the Use of the Electronic Presentation System for the Reduced Sample (N = 27)[a]

Measure	Mean technical manual	Mean computer	F(1,68)	p
Time to faulted card (min)	45.6	22.4	20.77	.01
Time to faulted component (min)	28.5	22.6	3.99	.06
Total time to solution (min)	74.1	45.0	20.56	.01
Test points checked	3.5	5.0	13.31	.01
Components checked	8.8	11.5	3.86	.06
Total tests performed	12.3	16.5	8.34	.01
False replacements	0.8	0.0	11.79	.01

[a]From Nugent et al., 1987, p. 8.

Questionnaire Results. The results of the analysis of the responses to the 31 items in the posttest questionnaire are summarized in Table 9. For analysis purposes, the questions were grouped into four areas: physical, information presentation, efficiency, and effectiveness. A mean response for each category was then computed. The system was consistently rated "highly satisfactory" to "outstanding" in the physical category. The only exception was the adequacy of the screen size, which was rated as "satisfactory" (mean = 3.2). The adequacy of the technical information presented and access to that information was rated very high (mean = 4.22). The CMAS II was perceived as being more effective and more efficient than the paper technical manual.

Table 9. Summary of User Questionnaire Evaluation[a]

Feature	Questionnaire items	Mean
Physical	1 - 16	3.95[b]
Information presentation	17 - 24	4.22[b]
Efficiency	25 - 27	1.68[c]*
Effectiveness	28 - 31	4.38[b]

[a]Adapted from Nugent et al., 1987, p. 9.
[b]Scale Values: 1 = unsatisfactory, 5 = outstanding.
[c]Scale Values: 1 = significantly less, 5 = significantly more.
*The low mean for items 25 - 27 is a positive response.

Structured Interview Results. The responses of the 36 subjects in the structured interviews also reflected very positive attitudes toward the CMAS II. The responses are summarized in Table 10. Data are not provided for interview items 1, 2, 8, and 9, since few, if any, responses were received to those questions. Responses of all participants were combined for the analysis, since no differences were noted among the members of the three services or between experience levels.

Table 10. Summary of Technicians' Interview Responses[a]

Item	Response	n	Percent
#3 Level of detail			
a. Switching ease (between levels)	Yes	31	86
b. Two levels sufficient	Yes	34	94
c. Performance	Less detail	9	25
	More detail	14	39
#5 Like about Grid	Quick easy access to information	15	42
	Proceduralized: easy to go from one point to another	12	33
	Deletes excessive narrative; direct path to fault	9	25
	Reduces troubleshooting time	8	22
	Ease in switching among frames	7	19
#6 Not like about Grid	Cannot see entire schematic on the screen	17	47
#7 Mode preference	Grid	27	75
	Paper	1	3
	Both	7	19

[a]Adapted from Nugent et al., 1987, p. 10.

Analysis of the interview comments yielded the following observations:

1. The multiple levels of detail feature was a highly valued feature of the automated presentation system. Experienced and inexperienced technicians generally showed no difference in their preference for a more- or less-detailed presentation. The less-detailed presentation was seen as more appropriate for presenting simple procedures and for troubleshooting. The more-detailed procedures were seen as appropriate for presenting extra information for inexperienced personnel and for providing parts information.

2. The technicians generally felt that the computer system was more effective in presenting information for troubleshooting than the paper system. The primary dislike was the presentation of schematics. This complaint was primarily due to the inability of the system to present the complete schematic for viewing at one time.

3. The computer was preferred over the paper technical data by 75% of the participants; 19% percent indicated they would prefer having both systems. The latter preference was based upon the rationale that the paper manual would be used to present schematics and the computer would be used to provide instructions for corrective maintenance. Also, 3% of the technicians indicated that they felt theory of operation and functional descriptions were more adequately presented by the paper technical data.

Conclusions

Based upon the results of the study, the authors (Nugent et al., 1987, p. 12) concluded:

> ...the results demonstrate that computers can be used as an effective means to present technical information in an electronic presentation format. If the technical information data base is constructed for ease of access, as was the RT-728A/APX-64(V), maintenance performance in terms of less time and errors should improve. More importantly, technicians appear willing to change to a different delivery method for obtaining maintenance information.
>
> Since the data base was very limited in the present effort, future evaluations need to address extremely large technical information data bases that offer many ways of entering and branching to the various types of information within those data bases.

Discussion

The CMAS II effort demonstrated that an automated system for presenting technical data is feasible for intermediate level maintenance. In addition, it demonstrated that such a system, if properly designed, will be accepted and used by technicians. In both the Grissom AFB demonstration and the NPRDC study, technicians were able to perform maintenance tasks at least as effectively (and in some cases more effectively) when using the automated system as when using the paper technical data. In both cases, the technicians indicated a preference for the automated system.

The CMAS II is only a prototype system. However, it does provide the basis for a number of recommendations for the development of automated technical data systems for operational use. These recommendations are discussed in detail in Section VII. Although the prototype proved to be an effective system, there are a number of design issues which require further research. These issues are also discussed in Section VII.

VI. PORTABLE COMPUTER-BASED MAINTENANCE AIDS SYSTEM

The overall objective of the computer-based maintenance aids project has always been to develop a system that is suitable to support both flightline and intermediate level maintenance. The earlier CMAS I and II efforts were all directed toward the development of a system for intermediate level maintenance. The Portable Computer-based Maintenance Aids System (PCMAS) effort was established to extend the technology for flightline maintenance and to develop the requirements for an operational automated technical data presentation system.

Concurrent with the development of the CMAS I and CMAS II studies, work by the Laboratory was in progress in three other areas which led to a broadening of the goals of the PCMAS project beyond the presentation of technical data. The areas were: (a) aircraft battle damage assessment (ABDA), (b) automated diagnostics for on-aircraft maintenance, and (c) integration of maintenance information systems. The areas of research and their impact on the PCMAS are described briefly below.

The ability of the Air Force to support sustained combat operations will depend to a large degree on its ability to rapidly repair battle-damaged aircraft and return them to operational status. Perhaps the most difficult aspect of the aircraft battle damage repair (ABDR) process is the assessment of the damage. It has been proposed that an automated technical data presentation system capable of providing special ABDA technical data could make a significant contribution to the assessment process. Such an aid would provide the assessor with information which presently is not readily available (e.g., times required for typical repairs, identification of mission critical systems, data on integration of systems, location of critical structures). In addition, it could provide rapid access to information that is presently available from TOs but is difficult to locate. (The information required to assess damage to one portion of the aircraft may be spread throughout the entire set of TOs for the aircraft, requiring hours of searching to locate.) It was also suggested that such an aid may speed up the assessment process by providing the assessor with detailed "peel-away graphics" which would allow him to determine if there are critical systems or structures located in, around, or behind the damaged area without removing panels or components.

Work was in progress to develop a joint project with the Air Force Flight Dynamics Aircraft Battle Damage Repair Program Office to develop an automated ABDA aid when it was realized that the necessary capabilities could be provided by the PCMAS (which was also in concept development). Therefore, an agreement was reached with the Flight Dynamics Laboratory to evaluate the PCMAS as an ABDA aid. The agreement provided for AFHRL to manage the effort and for the Flight Dynamics Laboratory to provide technical support and partial funding for the effort.

For several years, the Laboratory has had a project in progress to develop automated fault diagnostic techniques for on-aircraft maintenance. The approach developed calls for the use of a small, ruggedized, portable computer to connect directly to the 1553 data bus of the aircraft to interrogate aircraft systems and retrieve test and performance data. The portable computer would then use the aircraft data with automated diagnostic routines to diagnose faults in the aircraft's systems. The technology has progressed to the point that it is ready for testing. During the development of requirements for the PCMAS, it was recognized that the PCMAS (as then envisioned) would have the capabilities required for the diagnostics evaluation, with the exception of the ability to connect to and interact with the aircraft data bus. The addition of this capability to the PCMAS was deemed feasible. Therefore, a decision was made to include a requirement for a 1553 bus interface capability in the PCMAS and to use the PCMAS for the planned diagnostics evaluation.

A long-range Laboratory project is developing the Integrated Maintenance Information System (IMIS). The IMIS will provide a common interface to a number of information systems used in maintenance. The systems to be covered include: (a) the Automated Technical Order System (ATOS), (b) the Core Automated Maintenance System (CAMS), (c) supply systems, and (d) automated training systems. The IMIS program is presently in the concept development stage. Studies are planned to examine several issues and possible technical approaches to be incorporated in the IMIS. A small, rugged, portable computer is required for this purpose. The PCMAS has the capabilities required for many of the proposed studies. Requirements of the IMIS program have been considered in developing the PCMAS to ensure that the required versatility is provided.

Program Goals

The PCMAS program had the following goals:

1. Develop a small, rugged portable computer with the capability to:

   a. Present automated technical data for use on the flightline;

   b. Present specialized ABDA technical data;

   c. Interact with the aircraft MIL-STD-1553 data bus, extract data from the bus, and run automated diagnostic routines; and

   d. Serve as a testbed for studies in support of the development of the IMIS.

2. Adapt technical data presentation techniques developed for intermediate level maintenance to present technical data for on-aircraft maintenance.

3. Develop MMI techniques for use with a portable computer to present technical data, ABDA data, and diagnostics data for on-equipment maintenance.

4. Evaluate the PCMAS as an automated technical data presentation system.

5. Evaluate the PCMAS as an ABDA aid.

6. Provide PCMAS units for use in the diagnostics and IMIS studies.

Development of System Requirements

Both in-house and contractor efforts were used to develop system requirements. Surveys were made of the available state-of-the-art computer technology to ensure that the requirements established were practical and feasible within available resources. Technical data requirements were based upon experience in earlier efforts in the CMAS program. The ABDA requirements were based upon in-house efforts and a contractual effort by McDonnell-Douglas (Wilper, Eschenbrenner, & Payne, 1983). Requirements for the diagnostics capabilities were based upon ongoing in-house work to develop improved automated diagnostics techniques. An "A Specification" detailing the technical requirements for the portable unit was developed under contract by Systems Exploration, Inc. (Systems Exploration, Inc., 1984). This document was used to establish contract technical requirements for the PCMAS hardware and software.

System Development

A contract was awarded on 31 July 1985, to Boeing Military Aircraft Company, Huntsville, Alabama, for the development of the PCMAS. The contract called for the development of:

1. The PCMAS computer hardware (three units, with an option for an additional five units).

2. System software for the PCMAS (a UNIX-based operating system with utilities).

3. Applications software (for presentation of technical data; automated diagnostics; and specialized ABDA data, including peel-away graphics).

4. Sample routine maintenance technical data for a subsystem of the F-16.

5. Sample ABDA technical data.

Project Status

Work on the Boeing contract has been completed. The PCMAS hardware and software have been delivered. However, contract funds ran out before the hardware could be fully tested and before all known "bugs" in the software could be resolved. Work is presently in progress to evaluate the PCMAS hardware to determine if additional modifications are required. In addition, the software is presently being evaluated to identify problem areas. Necessary modifications to the hardware and software will be made in-house with some contractor support. Also, when the problems have been corrected, additional units will be constructed for use in planned field tests. The new units will incorporate an improved graphics board and a refined central

processor board, which have become available since the original units were constructed.

System Description

The complete PCMAS consists of a small, portable, ruggedized, general-purpose computer; peripheral units (which with the computer comprise a workstation); system software; and applications software. The system is designed to operate in two modes: with the portable computer in a stand-alone mode (for use on the flightline), and with microcomputers in a workstation mode (for use in the shop and for software development). The system specifications are presented in Table 11. The components of the system are described below.

Table 11. PCMAS Specifications

Feature	Specification
Dimensions	15 x 12 x 3 inches
Weight	13 pounds
Power consumption	46 watts without 1553 bus 52 watts with 1553 bus
Memory	
Internal	
CMOS RAM	2.0 megabytes
EPROM	1.5 megabytes
Removable cartridge	1.0 megabyte CMOS RAM
Processor	
Manufacturer/model	Motorola 68010
Clock speed	10MHz
Display	
Type	Electroluminescent
Active display area	7.68 x 3.83 inches
Resolution	512 x 256 pixels (66.6 pixels per inch)
Keyboard	
Stand-alone mode	Special purpose 10 numeric keys 8 function keys 4 cursor keys Enter key Backspace key Select key
Workstation mode	Modified VT-100

Table 11 (Concluded)

Feature	Specification
Voice recognition	
Type	Speaker dependent
Capacity	Recognizes 100 words
Accuracy	95% recognition in 85 db noise
Recognition speed	Less than .5 second
Microphone	Hands-free headset
Power sources	
Battery pack	3 hours
28 VDC	Aircraft power (28 VDC)
12 VDC	Adapter (28 VDC output)
110 VAC	Adapter (28 VDC output)
Interfaces	
Stand-alone mode	
1553 bus	MIL-STD-1553B
Workstation mode	Standard
RS-232	Standard
Centrex	
Ruggedization	
Shock	Withstand 3-foot drop
Temperature range	32 to 100 degrees F
Moisture	Operate in 20-95% humidity Operate in rain w/ 20 mph wind
Atmospheric pressure	Operate at 6,000 feet
Oil/chemical/dirt	Resist dirt, oil, fluid spills Operate in chemical environment

Hardware

Portable Computer. The portable computer (Figure 51) was designed and built specifically for this effort. Off-the-shelf components were used where possible. However, some major modifications and redesign of some components were necessary. The system is designed to be convenient to use on the flightline. It is lightweight, compact enough for easy handling, and easy to operate. It is sufficiently rugged to withstand the rigors of testing under a variety of operational conditions on the flightline. However, it is not designed to meet full military specifications for ruggedization.

The PCMAS portable unit display is an electroluminescent (EL) panel. The EL panel is a light-emitting display. It provides a wide angle of view (30 degrees) and is suitable for use under most lighting conditions. However, problems are encountered in direct sunlight. To overcome this problem, the display is laminated with a polarizing material, and a shade is provided. The EL panel has a moderately high resolution (66.6 pixels per inch) and is suitable for presenting graphics of the type required for technical data. The EL panel used for the PCMAS portable unit is very similar to the panel used in the Grid Compass Model 1139 computer used for CMAS II.

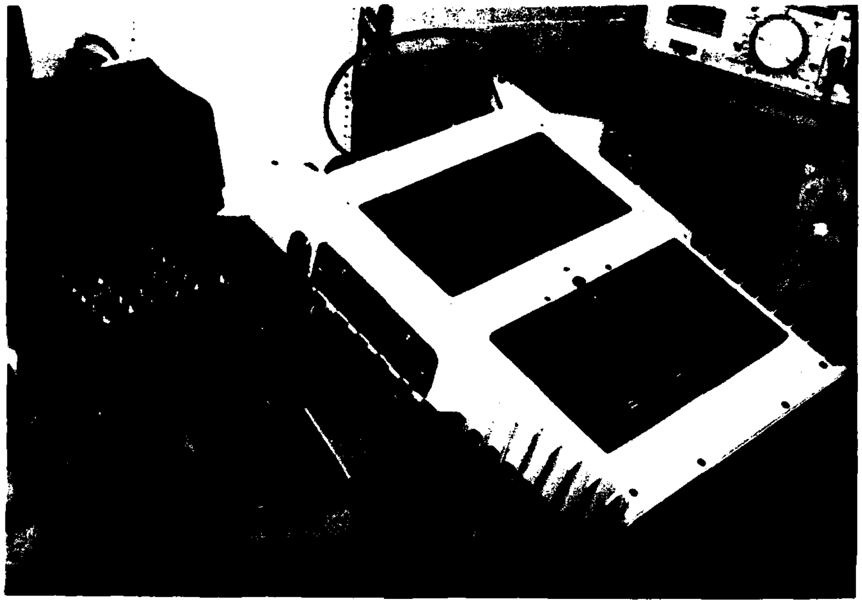


Figure 51. Portable Computer-Based Maintenance Aids System.

A special-purpose keypad was developed for the PCMAS portable unit. The keypad provides a standard numeric keypad for entry of numeric data, programmable function keys for controlling data recall and presentation, cursor control keys, an enter key, a backspace key, and a select key for data input. A capability to input alphabetic characters is provided using a menu select technique (the cursor and select keys are used to select alphabetic characters displayed on the screen). The keypad is sealed to provide protection from fluid spills.

Technical data for presentation on the portable computer are stored in interchangeable auxiliary memory modules. In addition to storing technical data, the memory modules can be used to record information developed during the maintenance task (such as task performed, time to complete the task). This task can be downloaded to the workstation or another data base when the task is completed. In addition, the memory module may be used to store applications programs that are not maintained in the built-in EPROM (electronically programmable read only memory). The initial auxiliary memory modules have a capacity of 1 megabyte. It is anticipated that advances in memory technology will make a 6-megabyte module possible in the near future.

A built-in MIL-STD-1553B bus interface provides a capability to communicate directly with on-aircraft systems for aircraft equipped with a MIL-STD-1553B data bus. The 1553B interface is capable of performing as a bus controller, remote terminal, or as a bus monitor on a 1553B data bus. This feature will make it possible for the PCMAS portable unit to interrogate the aircraft's built-in tests (BIT) to obtain performance data. The PCMAS portable unit then can use this information, with its internal diagnostic routines, to diagnose system faults.

The PCMAS portable unit operates on 28 VDC from any of four power sources: an external battery, aircraft power, a 12-VDC adapter, and a 110-VAC

adapter. The PCMAS battery uses 18 1.49-VDC Silver-Zinc cells assembled in a battery pack. The battery pack is external to the PCMAS unit. A 6-foot cable is provided with the battery pack, which connects directly into the unit. The battery pack is rechargeable and has a battery life between 50 and 100 cycles. The PCMAS computer will operate for 3 hours from the battery pack.

Workstation. The PCMAS workstation consists of the portable PCMAS unit, a junction box, a modem, a Winchester disk drive, a keyboard, and printer. The workstation can be interfaced to a Sun Microsystems workstation for use in data development, in software development, or to simulate communications with other computer systems. The workstation mode is provided for:

1. Developing and/or modifying software.

2. Loading data onto auxiliary modules from the Winchester disk drive.

3. Interfacing with other computer systems.

4. Downloading data from the auxiliary memory module to the Winchester disk drive or to other computer systems.

5. Printing data or software from the auxiliary memory module, from the Winchester disk, or from another computer system.

The PCMAS portable unit connects to the workstation via a specially developed junction box. The junction box contains connections to the keyboard, the Winchester disk drive, a Sun workstation, the printer, an auxiliary display, and the modem. In addition to the PCMAS portable unit, the following equipment is included as part of the PCMAS workstation:

Junction Box: Developed by Boeing specifically for this application.

Disk Drive: Javelin Emulex, Model ED2/40-T Winchester disk drive, with a streaming tape cartridge tape drive.

Keyboard: Digitran, Model 220-8.

Printer: Okidata Microline, Model 192 Personal Printer.

Modem: Datec, Model PAL 212 (300/1200).

Software

Two basic types of software were developed for the PCMAS: operating system software and applications software. Commercially available software was used where possible and cost effective. In those cases where new software development was required, the software was developed on a Sun workstation and transported to the PCMAS. (A system requirement was that software developed on the Sun workstation run on the PCMAS without modification.) The software available for the PCMAS is described briefly in the following paragraphs.

System Software. The PCMAS operating system is a kernel of the Berkley UNIX 4.2 operating system. The operating system contains only those functions of the UNIX operating system required to support the PCMAS.

Applications Software. Applications software was developed or is under development for the presentation of technical data, for interaction with the aircraft 1553B data bus, and for presentation of diagnostic procedures. It is anticipated that additional applications software will be developed for studies in areas such as the presentation of training and maintenance data collection in support of the IMIS program. The following paragraphs provide a brief description of software packages developed or under development for use with the PCMAS:

1. Boeing Presentation Software. As part of the PCMAS contract, Boeing developed software for the presentation of technical data. The software provides essentially the same capabilities as the CMAS II software with the addition of a rescale (or zoom) capability. In addition to the presentation software, limited software was developed for the creation of data for presentation on the PCMAS. The capabilities of this software are limited. As a result, the creation of data for presentation using this software is a labor-intensive task.

2. Boeing Maintenance Diagnostics Information System (MDIS) Software. The Boeing Company had previously developed software for an automated diagnostic system. The MDIS software was transported to the PCMAS to provide an automated diagnostics capability. However, the MDIS software is proprietary. This limits its usability since modifications required to operate the software with the 1553B bus are not possible without additional contractual arrangements with Boeing.

3. AFHRL Authoring and Presentation System (APS) Software. AFHRL is developing a system for authoring and presenting technical data for use with an automated system. The system is designed to use a "neutral" data base which is suitable for presentation on a variety of computer systems without modification of the data. The presentation software will be adapted for use with the PCMAS. This will make it possible to use the PCMAS to present technical data from the neutral data base.

4. AFHRL Diagnostics Software. In a combination in-house/contract effort, AFHRL has developed software for an advanced approach to automated diagnostics. This software will be transported to the PCMAS and expanded to incorporate the capability to interact with the 1553B bus.

Planned Efforts

PCMAS Technical Data Evaluation

An evaluation of the PCMAS for delivering technical data for routine maintenance is scheduled for the Spring of 1988. For this effort, technical data for the Chaff/Flare Distribution System of the F-16 will be converted to an automated data base using the AFHRL Authoring and Presentation System. These data will then be used with the PCMAS to evaluate the PCMAS as a device for presenting technical data for use on the flightline. Items of concern will include:

1. The degree to which the system is accepted by the user.

2. Identification of any problems encountered in using the system on the flightline (problems in reading the display, finding a suitable place to locate the unit while working, etc.).

3. The effectiveness of the PCMAS for presenting technical information.

4. Identification of potential improvements of the system.

ABDA Evaluation

The PCMAS will be used with a special ABDA data base to evaluate the concept of an automated ABDA. An ABDA data base will be developed for a section of an F-4 aircraft. The PCMAS and the data base will then be evaluated as an automated ABDA by having battle damage assessors use the PCMAS to assess a damaged F-4 aircraft. The study will examine:

1. The effectiveness of the PCMAS for presenting the required data.

2. The adequacy of the ABDA data base.

3. Problems involved in using the PCMAS in the battle damage assessment environment.

4. The acceptance of the system by the battle damage assessors.

5. Identification of potential improvements in the PCMAS.

Diagnostic Evaluations

Two studies will be accomplished to evaluate the PCMAS and AFHRL diagnostic techniques. In the first study, software will be developed to adapt the AFHRL diagnostic algorithms to use data from the F-16 data bus. Diagnostic and technical data bases will be developed for two or more subsystems of the F-16 which are serviced by the 1553B data bus. The data bases will then be used to evaluate the PCMAS and diagnostic algorithms as diagnostic aids. This will be accomplished by having technicians use the system to diagnose known faults in the testbed subsystems.

In the second study, a similar evaluation will be accomplished in a joint effort with the Navy using the A/F-18 aircraft as a testbed. The A/F-18 is a newer aircraft, with more sophisticated electronics and improved self-test capabilities. Use of the A/F-18 will allow the evaluation of diagnostic capabilities not available on the F-16. Software will be developed to adapt the diagnostic algorithms to use data from the A/F-18 data bus. Technical data bases will be developed for two or more subsystems of the A/F-18 which are serviced by the 1553 data bus. The data bases will then be used to evaluate the PCMAS and algorithms as diagnostic aids. This will be accomplished by having technicians use them to identify faults in the aircraft. The evaluations will examine:

1. The effectiveness of the PCMAS and diagnostic routines as diagnostic aids.

2. The problems involved in using the PCMAS as a diagnostic aid.

3. The acceptance of the PCMAS by the technicians.

4. Potential improvements of the PCMAS as a diagnostic aid.

VII. DISCUSSION

This project has clearly demonstrated that a computer-based maintenance aids system is feasible. It has shown that such a system is well received by the technicians who will use it and that technicians can effectively use an automated system to perform maintenance. In addition, it has provided evidence that technicians are able to perform intermediate level troubleshooting on electronic equipment more effectively when using an automated technical data presentation system than when using conventional TOs.

The CMAS II system was shown to be an effective system. However, it must be considered a first-generation automated technical data presentation system. Although some preliminary prototyping was done, the design CMAS II is largely based on logical analyses of the requirements for, the potential approaches for, and problems of presenting technical data on an automated system. The time and resources were not available to conduct detailed design studies to resolve each design issue. As a result, most of the features of the CMAS II are based upon the best judgments of researchers who are familiar with state-of-the-art techniques for presenting technical data, MMI techniques, human factors technology, and computer science ("given what we know about the problem and similar applications, we think that this is the best way to do it"). In some cases, system features and capabilities were determined by the limitations of the computer technology available at the time. Fortunately, most of the judgments made in designing the CMAS II were correct, and the system concept was proven to be successful.

It is recognized that the CMAS II is not the ultimate system. It is a system that has been shown to work and is as advanced as any system known to be in existence today. Although it is not the "ultimate" system, it should be considered a starting point for the development of more advanced systems. Its features should definitely be considered in the development of any system planned for operational use in the future.

Observations/Conclusions

The development of the CMAS II and its predecessors has provided a great deal of valuable information relative to the development of automated technical data presentation systems. It provides the basis for further refinement of the technology and for the development of systems for operational use. Some key observations and conclusions from the project are discussed below.

User Acceptance. Maintenance technicians will accept an automated technical data presentation system, provided it is easy to use and effectively meets their needs for information. It is essential that the system meet the technicians' needs at least as well as the paper-based system. The experience

with the CMAS I at Offutt AFB clearly demonstrated how rapidly the technicians will reject an automated system that does not meet their needs.

There are several factors which affect user acceptance. Response time is a critical factor. The technician will not wait very long for the system to present information. Acceptable times between the request for and display of information are not well defined. The "acceptable" time appears to vary with the type of data being requested. For recall of the next frame in a sequence of data (such as a sequence of procedural frames), only short times (less than 5 seconds) would be tolerated. Technicians seem to be willing to tolerate longer delays if they realize that information requested is for a different type of data, must be retrieved from a different part of the data base, or is a large file (such as a schematic) which requires longer to load. The field tests conducted in the project provided only tentative information on acceptable time delays since the technicians had the opportunity for only limited use of the system. Their reactions may be quite different with continued exposure in an operational setting. It is clear, however, that a rapid response time is critical to the acceptance of the system. It is likely that technicians will become much less tolerant of long delays when working under the pressures of the operational environment.

Ease of use is essential for user acceptance. The actions necessary to retrieve a given piece of information should be logical and somewhat obvious. They should not be cumbersome or require unnecessary steps (e.g., the CMAS I requirement to respond "yes" or "no" to the use of the graphics mode before going to the next frame). They should require a minimum of keystrokes for any action. Its simplicity of use was a major reason for the success of CMAS II.

The MMI techniques used in the CMAS II were effective and made important contributions to the acceptance of the system. They made the system easy to learn and use. The technicians experienced very little difficulty in using the system after a few minutes of training and practice. The MMI techniques provided the flexibility to move rapidly in the data base and retrieve all required information. This flexibility eliminated the "trapped" feeling reported by technicians using the CMAS I.

Accurate technical data are essential to user acceptance for automated technical data presentation systems. Errors in the technical data were critical factors in the rejection of the CMAS I by the technicians. Technical accuracy is essential for all technical data, but it is an especially difficult problem for automated technical data presentation systems since there are many more opportunities for error. This is due to the requirement to include codes to control branching to the next frame or optional frames of data. Branching errors can be critical if they cause the technician to get lost in the data base or, even worse, cause him to skip a critical step. Quality control for branching sequences is very difficult to adequately accomplish. Given the flexibility built into an automated system, it is practically impossible to check every possible branching sequence for accuracy. The use of automated authoring aids to assist in inserting and verifying the accuracy of branching instructions is the most promising (though untried) approach to resolving this problem.

The acceptance of an automated system by the technicians is facilitated by the relatively high computer literacy of Air Force maintenance personnel.

These personnel are used to working with high technology equipment and are not awed by the computer system, as might be the case with a less sophisticated group. Many technicians have home computers and are very knowledgeable of computer systems. This computer literacy could, in fact, be a potential problem since future "hackers" may find the temptation to tamper with the system irresistible. Appropriate safeguards will be required.

System Efficiency. The project has demonstrated that an automated technical data presentation system can effectively present technical data for use by maintenance technicians. It has provided evidence that such a system can provide information at least as effectively as a paper-based system and, for at least some applications, more effectively. However, much more data are needed to permit firm conclusions on this issue. The AFHRL and NPRDC field tests of the CMAS provided valuable information on the issue. However, the tests were not adequate to provide firm answers. The tests used very small samples of tasks and were limited to an electronic system. In addition, the troubleshooting procedures were designed to isolate known faults. To provide comprehensive and final answers, study is needed which:

1. Uses a larger sample of tasks (remove and replace, alignment, checkout, troubleshoot, etc.).

2. Uses data from different types of systems (electronic and mechanical systems).

3. Uses data for a complete subsystem. These data should be developed using the procedures that will be used for development of automated data for operational application. Troubleshooting data should cover all identifiable failures.

4. Compares performance using the automated system with performance using paper-based conventional technical manuals, Job Guide manuals, and fault isolation manuals. (Comparison of performance with Job Guide manuals and fault isolation manuals is necessary to ensure that gains in performance are not simply due to reformatting rather than to presentation on the automated system.)

Recommendations for a Next-Generation System

As indicated above, the CMAS II cannot be considered the ultimate system for the storage, retrieval, and presentation of technical data on a computer display. As the technology develops, significant improvements will be made. However, the CMAS II and the other research efforts conducted under this project do provide a sound basis for recommendations for the development of the next-generation automated technical data presentation system. Recommendations and guidelines for the development of future automated technical data presentation systems are provided in the following paragraphs.

Response Times

The optimal time to retrieve and display the "next" frame of procedural data in a sequence should be 1 second or less, and should not exceed 2 seconds. The time to display a large graphic should not exceed 5 seconds.

The time to retrieve data for a new procedure or from another part of the data base should not exceed 5 seconds. As a general rule, response times should be kept to the minimum that the hardware and software can support. An "instantaneous" response is not too fast.

Data Base Manipulation

The system should provide maximum flexibility to permit easy retrieval and manipulation of data from the data base. As a general guideline, the minimum number of keystrokes should be required to achieve any required action. In most cases, no more than one keystroke should be required to retrieve the next piece of information (i.e., next frame of data, next menu, etc.).

Data Access Methods. The following methods should be provided for locating and accessing information in the data base:

1. Menu Access. The user should be able to access any desired information from a series of top-down menus (system general to system specific). The number of menus required to identify the information should not exceed four in most cases. The number of items per menu should not exceed 10 to permit selection of an item with the press of one numeric key. An alternate approach for selecting from the menu is to use the cursor and select keys to make a selection. However, this process requires more actions by the user and is much slower unless a mouse or other device which provides for quick cursor movement is used.

The number of menus required to identify a specific piece of data is, in part, a function of the level that the menu system is entered (e.g., starting with a menu for the overall aircraft versus starting with a menu for a specific subsystem). As a means of limiting the number of menus which must be traversed, it is recommended that the capability be provided for the supervisor or system manager to specify the level of the first menu presented when the user signs on. For example, the supervisor of a radar shop could preset the computers in the shop to first present a menu for the radar systems maintained in that shop. An alternate approach would be to allow the users to specify the menu to appear as the first frame when they sign on to the system.

2. Direct Access. The system should provide the capability for the user to go directly to a given procedure or item of data by inputting a procedure title, section title, MIDAS code, part number, reference designator, frame number, or other unique identifier. In those cases where there may be more than one piece of information available relevant to an identifier, the system should respond with a menu identifying the available information for that identifier. The user should then be able to recall the desired information by selecting from the menu.

3. User-Defined Menu. The users should be able to "construct" their own menus tailored to their own needs. This will allow them to list only those items which are frequently used. The system should provide the capability to keep identifying this menu as their "main menu," which automatically appears when they sign on or when they press the menu or Table of Contents function key. Implementation of this capability should provide for the user-defined menu to always include the option to go to the system main menu or to the direct access mode.

4. Assignment Index Access. A capability should be provided for the supervisor to use the system to make work assignments. When the technicians sign on and select the assignment roster, they should be able to use the roster as a menu to select the data for their assigned task. (Note: A similar capability was included in the CMAS I system. However, it was not tested since the system was not used for actual maintenance tasks.)

5. IPB Access. The location of IPB information in the data base presents some special problems. The user may know the item nomenclature, part number, or reference designator. In this case, the desired information can be recalled using the direct access mode. If the system name, subsystem name, and assembly name are known but the name or number of the specific part is not, the menu system can be used to locate a drawing of the assembly. However, the user can go no further unless the item of interest can be identified and the specific information can be recalled. A "graphic" special menu is recommended for this purpose. An exploded view of the assembly can be used as the graphic menu. Callouts or other means can be used to identify specific parts. By entering the callout number or other identifier for the item of interest, the user can recall a detailed drawing of and parts information on the item.

Capabilities for Movement within the Data Base. Once the user has located the desired information, the system should provide extensive capabilities for movement within the data base to obtain additional information. The following capabilities should be provided:

1. Go to next step. A function key should be provided to go to the next step in a sequence. This function should be active except when the next step is based upon conditional branching or when the user is asked to select from a menu of options.

2. Back up in a procedure. A function key should be provided to permit the user to step backward in the procedure. Pressing the BACK function key should take the user to the preceding step in the procedure. Repeated pressing of the BACK key should lead the user to the first step of the procedure.

3. Go to previous step. A function key should be provided to return to the previous frame in a sequence. Repeated pressing of the RETRACE key should permit the users to retrace their steps through the data. This function should always be active.

4. Conditional branching. The system should have the capability to branch to the next appropriate frame as determined by the user's response ("yes," "no," or other input) to a question presented by the current frame.

5. Select an option. The system should allow the user to select from several options (identified by a footer at the bottom of each frame). In most cases, the option should be selected by pressing a function key. However, if there is more than one option available for that category of data, a pop-up menu should be provided listing the available options (e.g., if the users select a "diagrams" option, they may be presented with a menu listing schematics, functional diagrams, or wiring diagrams). In this case, the footer should indicate that options are available for a given type of data

(such as diagrams). The press of an options function key should retrieve the options menu. A pop-up menu is suggested.

6. Return after branching. A function key should be provided to allow the user to return to the same point in the data base after branching to another location in the data base. For example, if the user branched to a schematic, pressing the RETURN function should take him back to the frame from which he selected the schematic. If he branched from the schematic to the IPB, pressing RETURN should return him to the schematic. Pressing RETURN a second time should return him to the original frame.

7. Access other data. A function key should be provided to allow the user to return to the main (or other) menu or to select the direct access mode.

8. Go to next procedure. At the end of a procedure, the system should provide the opportunity for the user to go directly to the procedure for any required follow-on maintenance. Similarly, when a fault has been isolated in a troubleshooting procedure, the system should provide the user with an option to go directly to the procedure to correct the fault.

9. Change level of detail. For procedural data, a function key should be provided to give the user the capability to select a more-detailed or less-detailed presentation. The system should provide the capability for the supervisor to limit, as appropriate, the level of access available to a given user. This capability may be necessary to ensure that less experienced technicians do not use data intended for use by experienced technicians only.

10. Book mark. A capability should be provided to allow the users to establish a book mark at a given location in the data so that they may return directly to that point at a later time (either in the same session or in a future session) without going through the menu mode or remembering and inputting an identifier in the direct access mode.

11. Hold feature. A capability should be provided which allows the users to place a frame of information on hold while they examine a second frame and to switch easily back and forth between the frames.

Display Manipulation Capabilities. The following capabilities to change the manner in which selected information is displayed on the screen should be provided:

1. Scroll. The system should provide the capability for the user to "move" the display window over a drawing that is larger than the display. An icon should be provided to advise the user that the graphic is larger than the display and that the scroll function is active.

2. Rescale. The capability should be provided to allow the user to rescale (enlarge or reduce) graphics presented. Rescaling should be accomplished in a continuous fashion (i.e., the illustration should appear to "grow" or "shrink" before the user's eyes, as opposed to the screen being blanked out and the illustration redrawn at a larger or smaller size). An appropriate scaling factor should be used so that the difference in each succeeding iteration is not so large that the users must reorient themselves, but not so small that an excessive number of iterations are required to reach

the desired size. A limiting factor should be provided so that the illustration cannot be enlarged to a point that it is useless (e.g., enlarged until only a blank screen is seen) or made so small that it is useless (e.g., reduced to a single dot). An icon should be provided to inform the user that the rescale feature is available.

The capability to enlarge the graphic is needed in some instances where the user requires additional detail or must view the illustration from a distance. This feature is most useful for examination of IPB illustrations or complex diagrams such as schematics. The requirement for the use of this feature should be limited if the graphic is initially presented at an appropriate level of detail and size.

Computational capability. The system should provide a capability to perform calculations on data input by the user (at the system's request). The system should present the results of the calculations and, at the user's request, branch to the next appropriate frame based upon that result. This feature eliminates the requirement for the technician to perform the calculations by hand and reduces the risk of error.

Input capabilities. An effective automated technical data presentation system must provide a convenient method for the user to input a request or input data to the computer. Specially designed function keyboards should be provided for this purpose. Since requirements for in-shop and on-aircraft maintenance are somewhat different, separate function keyboards are recommended for the two applications. It is anticipated that shop applications will be used for housekeeping functions (recording maintenance actions, data base maintenance, etc.), as well as for presentation of data. Thus, the shop system will require a convenient method for inputting alphanumeric characters. Requirements for input of alphanumeric characters to the portable system are limited and can be met by other means (such as selection of characters presented on the display). Since space on the keyboard for a portable system is limited, it is suggested that the alphabetic keys not be included.

In many cases, the same technicians perform both in-shop and on-equipment maintenance. Thus, it is highly desirable that the keyboards for the shop and portable systems be as similar as possible so that the technician may switch "comfortably" between the keyboards. The function keys, numeric keys, and control keys should be placed in arrangements that are as similar (similar locations, similar order of appearance, etc.) as possible while still leaving room for the alphabetic keys on the shop-level keyboard. An option would be to use two keyboards: a function keypad for using the system as a maintenance aid, and a full alphanumeric keyboard for the occasional in-shop task which requires the input of a large amount of alphanumeric data or for housekeeping tasks. When not in use, the second keyboard would be kept in a convenient location out of the technician's way on the workbench.

In designing function keypads for in-shop maintenance and for on-equipment maintenance, the following requirements should be considered:

1. The space available on the shop workbench is limited. The keypad must be small enough to allow adequate work space. The space available on the portable unit is also very limited (and will become even more limited as

displays become larger). Thus, it is essential that the keypad be kept as small as possible.

2. The keyboard must be rugged and spill proof.

3. The keyboard for the shop should be connected to the computer system by a cable, so that it can be moved to the most convenient location on the workbench without moving the computer or display.

4. The keyboard for the portable unit must be suitable for use when wearing gloves provided with the chemical defense ensemble.

The most important components of the function keyboard are the function keys. It is recommended that a combination of programmable and "hard-wired" function keys be used. Hard-wired function keys should be used for functions that are always or almost always active. These include functions such as next, back, and data access. The remaining keys should be used for functions that are not always active, such as for schematic drawings and parts information. The allocation of function keys must be based upon an analysis of the requirements of the specific application. It is recommended that the programmable function keys for the portable system be placed in a row below the screen so that the function of the keys can be defined in a footer at the bottom of the display (1:1 correspondence). Hard-wired function keys need not be located at the bottom of the screen. However, they must be located in a convenient position and should be in a logical arrangement (i.e., grouped functionally, spatially, etc.). When an inactive function key is pressed, some type of feedback (such as an audible "beep") should be provided indicating that the function is not active. Also, a provision should be made for quick recovery if the user presses the wrong function key. A similar keyboard arrangement should be used for the shop system for consistency.

Although not evaluated in this project, two other data input devices should be considered. They are voice activation systems and touch panel systems. Voice activation systems have the potential to be an effective tool for automated technical data presentation systems. The technology is progressing rapidly. However, there are a number of problems which must be resolved, including the effect of ambient noise, poor recognition rates, and time required to "train" the system to recognize a specific user. Touch panel input systems are more nearly ready for application in automated technical data presentation systems. The primary concern is their durability and ability to withstand the inevitable rough treatment that the system will receive in the maintenance environment.

Presentation Formats

Proceduralized Data. Data for procedural information should be presented in a Job Guide-like step-by-step format (reference MIL-M-83495). Three basic types of information must be provided: (a) preparation information (input conditions); (b) procedures; and (c) warnings, cautions, and notes. The following format recommendations are made for use with automated technical data presentation systems:

1. Input Conditions Format. The input conditions frames should provide the technician with all of the information that is needed to prepare to perform the task. This information should include, as a minimum, applicable serial numbers; personnel required; parts information; supplies required, equipment conditions; and warnings, cautions, and notes. The input conditions should provide information in an uncluttered, list format similar to that illustrated in Figure 46.

2. Warnings, Cautions, and Notes. Warnings, cautions, and notes should be presented in an attention-getting format. Unique banners should be used to indicate that the information presented is a warning, caution, or note. Warnings, cautions, and notes may be presented on individual frames or, for large screens, presented on a frame with other information. When the latter approach is used, care must be taken to ensure that the warning, caution, or note stands out and cannot be missed. All warnings, cautions, and notes applicable to a procedure should be presented at the beginning of the procedure immediately following the input conditions and again immediately prior to the step to which they apply.

3. Procedural Data Formats. Procedural data should be presented in a step-by-step format. Data intended for use by inexperienced personnel should be supported by illustrations keyed to the text. Data for use by experienced personnel may or may not be supported by graphics, depending upon the nature of the data and the anticipated skills of the experienced user. Normally, experienced personnel will not require locator diagrams. However, they may require diagrams presenting test data (such as expected wave patterns on an oscilloscope). The allocation of space and arrangement of graphics and text in the frame are dependent upon the amount of textual data, number and size of illustrations, and the size and shape of the screen. The arrangement of the data on the frame should be uncluttered and easy to read. See Figures 44 and 45 for examples of typical formats.

Non-proceduralized Data (text). Textual information (such as theory of operation, system descriptions, etc.) should be presented in a blocked text format. Information should be displayed in an uncluttered, easy-to-read arrangement. Specific layouts are dependent upon the nature of the information to be presented.

Large, Complex Diagrams. Large, complex diagrams, such as schematics and wiring diagrams, present a special problem since the complete diagram cannot be viewed on the screen at one time. The use of a pyramiding approach such as that tested in the Hughes/Rockwell design study (Section IV) is recommended. In this approach, an overall diagram identifying the basic functions or functional areas of the underlying diagram is presented first. The user is able to identify the function of interest. By entering an identifier or by moving a cursor to the appropriate block on the diagram, the user can then call up the needed portion of the diagram. The following recommendations are made for use of the pyramiding approach for the presentation of large, complex diagrams:

1. The overall functional diagram should be presented at a size which is easily readable without rescaling. If the number of functions to be represented are too large for presentation on the screen, multiple levels of functional diagrams may be used. However, the number of multiple-level function diagrams should be limited (preferably no more than 3 or 4).

2. After the user has made a selection from the functional diagram, the portion of the diagram providing detailed information on the function selected should be presented on the display. The scroll function should be active so that the user can move the diagram to display information not initially displayed. The scroll function should allow the user to scroll the diagram into the next functional area to permit tracing of signal flows and interrelationships between functional areas.

3. Provision should be made for ready access (from the detailed diagram) to the functional diagram to assist the users in maintaining their orientation. Access may be provided by presenting the functional diagram in a second window on the display or by providing rapid switching back and forth between the diagrams. If the windowing approach is used, the functional diagram must be presented at a size that permits the data to be read without enlargement. Also, when windowing is used, the functional diagram window must be "active" so that the user may manipulate the diagram or select a different function for detailed display.

IPB Data. Two basic formats are recommended for IPB data: an exploded view format and a parts information format.

1. Exploded View Format. The exploded view format has two functions: to illustrate the components of an assembly and their interrelationships, and to serve as a graphic index. Multiple levels of exploded views may be used so that, where appropriate, an exploded view of the next-level subassembly may be recalled. The exploded view should fill the full frame. Each item shown on the illustration should be identified by a callout which can be entered into the system to recall detailed information on the item. In addition, an option should be provided to recall information on the assembly as a whole and, where appropriate, the next lower subassembly.

2. Parts Information Format. This frame should provide a detailed illustration of the part in one section of the frame and a listing of pertinent information about the part (part number, reference designator, stock number, etc.) in another window. The frame should provide the option to go to the exploded view of the appropriate assembly or subassembly. See Figure 41 for an example parts information frame.

Common Format Elements. All formats must contain the following elements:

1. Header. The header should present the TO number, procedure title, and a frame or other unique identifier. Other identifiers such as a MIDAS code may also be included if desired. This information should always be presented at the top of the frame.

2. Footer. The footer should be used to identify active function keys and to present system messages (such as "NEXT not active"). Function identifications should always appear on the last line of the display. System messages may be on the last line (writing over the function identifications) or on a line above the function identifications as appropriate.

Other Format Considerations. Consideration should be given to the following factors in developing formats for the presentation of technical data on an automated system:

1. Font size. The font used to present procedural data should be sufficiently large to be easily read at a distance of 6 to 8 feet. A smaller font (readable at 2 to 3 feet) may be used for support information (such as theory of operation) which is normally read at a closer distance. (Note: character heights of .250 and .125 inch are required for readability at 6 feet and 3 feet, respectively.)

2. Font Style. The font style selected should be clear and easy to read. Letters which are similar in shape (such as a, e, and o) should be easily distinguishable.

3. Case. A combination of standard lowercase and uppercase characters should be used. The upper/lowercase combination provides more information and is easier to read.

4. Font Generation. Preconstructed or "built-in" fonts should be provided for all fonts frequently used to present data to speed presentation of textual information. A requirement to "draw" each letter significantly increases the time required to present a frame of data.

Hardware Considerations

Hardware for shop and portable systems must perform essentially the same functions. However, the constraints for each environment present different problems for the designers of systems for each application. The following factors should be considered in designing hardware for automated technical data presentation systems for shop and flightline use:

Shop Systems. The constraints imposed by the shop environment provide fewer restrictions than the flightline environment in terms of physical size, power consumption, and environmental conditions (temperature, humidity, lighting, etc.). There are several tradeoffs to be considered in selecting hardware for a shop system. The following recommendations are provided:

1. Physical Characteristics. Limiting the physical size of shop systems is not as critical as for portable units. However, it is highly desirable that the hardware be kept as small as possible so that it does not crowd the technician's work space. The display should be as compact as possible. The display unit itself should fit conveniently on the workbench where it can be easily viewed from all work areas of the bench (30-degree viewing angle). The display unit should be as compact as possible. The hardware required to support the display (processors, graphics boards, etc.) should be located in a separate unit (located somewhere off the workbench) so that the display unit is composed only of the display itself and its mounting.

Other physical units of the system (processor, secondary memory, interfaces, etc.) should be located somewhere off the workbench. The exact location of these components is dependent upon the overall configuration of the automated technical data system (which may use dedicated units for each workbench or use a distributed system with a central processor supporting several shops or possibly the whole base) and is beyond the scope of this project. An option that should be considered for some applications is placing the complete unit (display, secondary memory, etc.) on a special cart (such as

that used for an oscilloscope) which can be moved in and about the shop as necessary.

For operational applications, the hardware should be sufficiently ruggedized to support operations in worldwide deployments or combat actions. The degree of ruggedization required for deployable test equipment should be sufficient for most applications. Also, it should be remembered that deployment requirements may add other constraints (power availability, packaging, etc.) which must be considered in system design.

2. Display. The screen must be of sufficient size to permit presentation of a meaningful amount of data in a readable form. It must be large enough to permit the use of a font that is easily readable and the presentation of graphics in sufficient detail for easy use. It must be remembered that, in many cases, the display must be read from as far away as 6 to 8 feet. Experience with the CMAS I and CMAS II and similar systems suggests that a display size of approximately 5 x 8 inches is adequate for most shop applications.

The display must have adequate resolution to permit display of relatively complex graphics. There are no firm standards for display resolution for technical data presentation. The display should have a medium level of resolution. Experience with the prototypes developed in this project indicates that the display should have a minimum of 65 pixels per inch. This level of resolution was found to be adequate for most graphics found in technical data.

The display should be easy to read under a variety of lighting conditions. To meet this requirement, it must have some provision to limit glare (through the use of a filter, shade, or repositioning); have a high contrast ratio; and have a large angle of view (at least 30 degrees) to permit the user to read from all work positions without repositioning the display.

3. Memory devices. The system should provide a hard disk memory device with sufficient capacity to maintain the data for all equipment maintained using the workbench. The amount of memory required is a function of the amount of information to be presented and the manner in which the data are prepared (coding scheme used, data compaction techniques used, etc.).

Portable System. Creative application of state-of-the-art technology is necessary to design a portable computer system suitable for the presentation of technical data in the flightline environment. The current state of the art will not support the development of the "ideal" portable system. Significant advances are needed to improve memory capacities; improve the size, resolution, and viewability of flat-panel displays (while limiting power consumption); improve processor speed; improve graphics generation and display capabilites; and increase battery capacity. However, the technology will support the development of portable systems which are satisfactory first-generation portable computer systems for operational use. The following recommendations should be considered in the development of such a system:

1. Physical characteristics. The system must be small enough and light enough for convenient use. A female technician qualifying for a maintenance career field should be able to pick up the unit (by the body, not the handle)

with one hand and hold it with one hand for at least 5 minutes. As design goals, it is recommended that the next-generation portable system not exceed 8 pounds in weight, and not be more than 2 inches thick, 10 inches wide, and 12 inches long.

The unit must be sufficiently ruggedized to withstand the rigors of flightline use and the most stringent environmental conditions expected to be encountered.

2. Display. The basic display requirements described above for the shop-level system are also applicable for the portable system. However, the constraints imposed on the portable system make the selection of a display a difficult problem. Additional factors which must be considered are described in the following paragraphs:

a. The power consumption must be limited due to the requirement to operate on battery power. Power consumption and battery capacity must provide for the computer to operate without recharging the batteries for at least 4 hours and preferably, 8 hours or longer.

b. The display must be suitable for viewing under difficult lighting conditions--ranging from near darkness to bright sunlight.

c. The display must be able to withstand very rigorous handling, including dropping from a height of 10 feet.

d. The display must be sufficiently thin to allow it to fit in the limited space available on the portable unit.

The above constraints limit the display to a flat-panel technology. At the present time, none of the flat-panel technologies is capable of providing a completely suitable display. However, rapid advances are being made in this technology area which may resolve the problem before a portable system is available for operational use.

3. Memory. The portable unit must have a secondary memory capable of providing the technician with all of the information needed to complete an assigned task without returning to the shop to "reload." The memory cartridge approach adopted for the PCMAS appears to be a satisfactory solution to this problem; however, it has not been fully tested. Future advances in memory technology may make it possible to store the required data for an entire system on board the portable unit without the necessity to rely on interchangeable cartridges.

4. Ruggedization. The portable system must be rugged enough to withstand the very rough treatment that can be expected in the flightline environment. It must be able to withstand extremes of temperature and humidity, rain and liquid spills, being dropped from several feet and various other shocks, and the effects of high-altitude operation. In addition, it must be shielded to prevent electromagnetic interference.

Software Considerations

The following software features should be included in any operational system developed:

Shop/Portable Systems Software Compatibility. To the maximum extent possible, the same software should be used for the shop and portable systems. The only differences in the software should be those necessary to accommodate:

1. Unique features or capabilities of each system (e.g., housekeeping functions for the shop system and interactive diagnostic functions for the portable system).

2. Characteristics unique to each system (e.g., different display and memory devices).

Software Capabilities. The following types of software should be provided for the shop and portable systems.

1. Operating System. A standard operating system (such as Unix) should be used. The same operating system should be used for the shop and portable systems. The complete operating system should be provided for the shop system. The operating system for the portable system should be a "pared-down" version containing only those features required to support the system's designated functions.

2. Applications Software. As a minimum, three types of applications software should be provided:

a. Data Presentation Software. This software should provide for the display of technical data including maintenance procedures, troubleshooting procedures (non-automated diagnostic routines), IPB information, and support information (theory of operation, system descriptions, etc.). The same basic software should be provided for both shop and portable systems. The software should be designed to operate from the same data base so that shop-level technical data may be displayed on the portable system and vice-versa.

b. Interactive Diagnostics Software. This software should be provided for diagnostic procedures which interact with aircraft systems. It is anticipated that this capability will be provided with portable systems only. However, future efforts may extend the techniques to interface shop systems to test equipment. In that event, the shop system will include diagnostics software.

c. Maintenance Data Collection (MDC) System. This software provides a means for the user to record and input information on maintenance actions completed to the MDC system. This software should be provided for both systems. (Note: Depending upon system design, MDC data may be transferred from the portable system to the MDC system via the shop system.)

The technical data presentation, interactive diagnostics, and MDC system software must be fully integrated so that they appear as one system to the user.

Other Considerations

Use of Color. Color can be useful to emphasize critical information (such as warnings) and to color-code other types of information (thereby providing additional information). However, there is little, if any, empirical data to suggest that the use of color for automated technical data presentation systems improves performance. Other applications of color for information systems suggest that the use of color for the presentation of technical data may be beneficial if properly applied. However, the ability to present data in color should not be a major criterion for selection of the hardware for such a system. For the initial system, it is more important to use a display that is large enough to present a meaningful amount of data in a readable size and with sufficient resolution. Additional research is needed to assess the value of color for the presentation of technical data.

Orientation. It is important that the users know where they are in the data base. The system should provide visual cues to help the users maintain their orientation. The primary tool available for this purpose is the header at the top of each frame. As a minimum, the header should provide the following information to the user: which TO is being used, the name of the procedure, an indicator showing the data track, and some step or frame identifier. In addition, an indicator should be provided to tell the user the relative position in the procedure (e.g., step 5 of 34).

Help. The system should provide ready access to a help function which provides guidance on the use of the system. The help feature should provide the following types of information:

1. Situation specific. Information on the current situation and the available options (this is where you are, and here are your options).

2. System Operation. An on-line instruction manual on how to use the system.

The help function should be accessed through a dedicated help key or through the main menu. The use of a dedicated help function key is desirable if the hardware provides sufficient function keys to allow one key to be set aside for this purpose and still satisfy requirements for other essential functions.

Research Needs

As indicated earlier, many of the design features of the CMAS II were based upon analysis and the developer's "best guess." Although the system based upon these best guesses has proven to be successful, it is likely that some of the features incorporated in the system are not optimal. A better understanding of the features and definition of requirements will result in the development of even more effective systems. Design features and design issues which require additional research are discussed below.

Graphics Issues

Graphics are critical elements of an automated technical data presentation. Several graphics issues require study.

Graphics Complexity. The issue of how complex graphics should be for automated technical data presentation is not well understood. Two factors are involved: usability and storage requirements. The graphic must contain enough detail to permit the user to identify the items of interest, but must not be so detailed that the item of interest is lost in a blur of lines. In addition, as a practical necessity, it is essential to keep graphics complexity to a minimum to reduce storage requirements. Preliminary findings indicate that much of the detail can be omitted from an illustration without a decrement in performance. Providing only limited cues seems to be sufficient in many cases to permit identification of the item of interest. Additional research is needed for a variety of applications to determine how complex graphics must be in order to support maintenance. Guidelines must then be developed to guide the technical data writer/illustrator to ensure that the appropriate level of detail is provided in all graphics and to ensure consistency of application across the data base.

Use of Graphics in Procedural Data. There is general agreement that, at least for inexperienced personnel, graphics should be provided to support procedural data. Two issues require study: (a) arrangement of text and graphics, and (b) the form of callouts used. One of the Hughes design studies examined the approach of integrating text and graphics (see page 67). Although the study indicated that the approach has promise, it was not conclusive. Additional studies of this and other approaches to arranging text and graphics are needed.

The concept of using callouts to key text to illustrations for procedural data has been demonstrated to be effective for paper-based systems (e.g., Job Guide manuals). In addition, it was successfully applied in the CMAS. There are at least two ways of keying callouts to the text. One approach is to use numbers in parentheses immediately following the item of interest in the text which correspond to a numbered arrow pointing to the item of interest in the illustration. Another approach is to use the number of the procedural step to refer to a numbered and labeled arrow pointing to the item(s) of interest in the illustration. Research is needed to evaluate the relative effectiveness of the two approaches and any other approaches which may be developed.

Use of Zoom/Scroll Capabilities. It is generally believed that an automated technical data presentation system should provide the capability to zoom and scroll selected graphics. Research is needed: (a) to determine the most effective techniques for controlling the zoom and scroll-features (e.g., arrow keys, joystick, mouse, etc.); (b) to establish the most appropriate scaling factors; and (c) to develop guidelines for specifying when the capabilities will be made available and for specifying the limits placed on their use.

Presentation of Schematics. The studies conducted under this project have shown that schematic and other large diagrams presented on a computer display can be used effectively, and have provided some suggestions on how they can be designed for more effective use. Potential techniques for improving the use

of schematic and other large diagrams include: (a) the use of pyramiding (see page 61); (b) the use of overview or function diagrams, (c) the highlighting of signal paths; and (d) computer-generated signal tracing (i.e., the user identifies a component and the computer identifies the components that that component is dependent upon).

Pseudoanimation. In the initial feasibility study, Frazier proposed the use of pseudoanimation to present procedural instructions for selected tasks (see page 21). The concept was not pursued at the time because it was considered impractical with the state of the art in computer animation at the time. However, significant advances have been made in animation technology which may make the technique worthy of further investigation.

Display Issues

The following display issues require study:

Resolution. The selection of an appropriate level of resolution for the display of an automated technical data presentation system involves two tradeoffs: cost and speed. The higher the resolution, the greater the cost of the display. The higher the resolution, the more computations that must be made and hence, the more time required to display a graphic. The optimum resolution for automated technical data system displays is not known. The CMAS studies indicated that the level of detail of the Grid Compass electroluminescence display (66 pixels per inch) is adequate for presenting technical data for electronic systems. However, electronic systems require relatively simple graphics. It is uncertain whether the same level of resolution will be adequate for the more complex graphics found in mechanical systems.

Display Screen Size. The optimum screen size for displays for in-shop and portable technical data presentation systems is not known. Screen size is not seen as a major problem for in-shop systems since space is not a major constraint (although there is likely an optimum size beyond which the advantages do not justify the cost or space usage associated with a larger screen). However, screen size is a major consideration in the development of a portable system, since it is a major determinant of the size of the unit itself. Preliminary test results (Dwyer, 1985) indicate that a number of factors (including graphics information density, discriminability of elements of a graphic, and display resolution) influence screen size requirements. Research is needed to identify the optimum size of a screen for portable and in-shop systems.

Use of Color. As indicated, the impact of the use of color for automated technical data presentation systems is not well understood. Research is needed to identify techniques to use color to improve performance when using an automated system. Once such techniques are developed, research is needed to evaluate their effect on performance to provide a basis for determining if the improvement in performance justifies the additional cost.

Other variables. There are a number of other factors (such as contrast ratios, brightness, font size, etc.) which influence performance when using a computer display. There are large amounts of data in the literature on

variables of this sort. However, most of the data have been developed under working conditions which are very different from those encountered in the maintenance environment. Thus, the data cannot be applied with confidence to the development of computer displays for use in the maintenance environment. Research is needed to evaluate each of these variables under conditions similar to those encountered in the maintenance environment.

Technical Data Presentation Considerations

Multiple Levels of Detail. Although the multiple level of detail or track concept was well received by the users and is believed to be an effective technique, there are several issues which require further study. A major question is how many levels of detail should be provided and how they should be defined. Experience in both CMAS efforts indicated that two tracks of data are sufficient for the intermediate level maintenance of avionics equipment. Because many of these tasks are relatively straightforward, it is difficult to provide enrichment to aid the novice (e.g., it is difficult to provide enrichment for a step such as "Turn MODE SELECT SWITCH to MODE A"). However, two levels of detail may not be sufficient for all types of maintenance. Some mechanical tasks, for example, may require three tracks to provide adequate information to the novice. Also, it may be that some portions of a procedure may require a third track while others require only one or two tracks. Research is needed to determine how multiple tracks are to be used, to define the multiple tracks to be used in automated technical data presentation systems, and to define the applications for which two or more tracks are appropriate.

A related problem is the question of how much detail must be provided in the minimum level of detail track (Track 1). The original concept was that this track would be for the very experienced technician who needed only a reminder of the basic subtasks which (it was assumed) he would know how to perform. (He could refer to the Track 2 procedure if he so desired.) However, in application, the question arises as to whether this level of detail is sufficient to satisfy safety and quality assurance requirements. Early indications are that, although very acceptable to experienced technicians, this level of detail may not be acceptable to safety and quality assurance officials. Research is needed to evaluate this problem and determine the appropriate minimum level of detail for Track 1.

Steps per Screen. Depending upon the amount of information to be presented, the size and number of graphics, and the size of the screen, it is often possible to put more than one step on a frame of procedural data. Presenting as many steps as possible on a screen has the advantage of reducing the number of times the technician has to stop and press the NEXT key. It also makes full use of the screen and avoids the possible complaint from the technician that the space could have been used to present the next step so that he would not have to stop and press NEXT. However, presenting only one step at a time has the advantage of forcing the technician to acknowledge each step and reducing the chance that he may inadvertently skip a step. A compromise approach is to present multiple steps per screen and highlight each step as it is performed. In this case, the technician is required to indicate to the system when the step has been completed. Research is needed to determine which approach is the most desirable.

Presentation of Diagnostics Information. The interactive diagnostic techniques being developed under the MDAS program, and their planned integration with the automated technical data presentation system, raise a number of issues which have not been adequately studied. Some questions which must be studied are:

1. What is to be the role of the technician in an interactive diagnostics system? How much of the diagnostic process should be performed by the computer and how much by the technician? How much control should the technician have (i.e., should he be permitted to select tests to be performed)?

2. For what experience level of technician should the system be designed? Should the system be suitable for both novice and experienced personnel? If so, what should be the differences in the way information is presented and the control provided to the technician? How much system knowledge can be assumed (e.g., is the technician a highly trained specialist or a generalist)?

3. How should the interactive diagnostics system be integrated with the technical data system? Should it be considered part of the technical data and be transparent to the user? Should it be a completely separate system which calls up technical data routines as needed? Who maintains the interactive diagnostics data (technical data personnel or diagnostics engineers)?

Pool Information. There is general agreement that the concept providing direct access to selected support or "pool" information (such as theory of operation or parts information) from a procedure is desirable. However, the question of what information and how much information has not been adequately answered. As originally proposed by Frazier (see page 15), the pool information was to include information (such as how to use test equipment) from outside of the basic technical order. This is a desirable concept. However, there are practical limitations which must be considered. The presentation of pool information other than the basic data procured with all weapon systems can be cost effective only if the pool information is already part of the technical data (which training data may not be). Another limiting factor is storage space, especially for portable units. Large fixed-base systems may be able to handle all of the information desired. However, at least until much larger capacity data storage devices are available, it will be necessary to limit access to pool information for portable systems. Research is needed to define what types of pool information are essential and cost effective and to develop criteria for determining what pool information is to be made available.

Man/Machine Interface Issues

Function Key Use. Further research is needed to determine how function keys are used. Answers are needed to the following questions:

1. How many function keys should be hard-wired and how many should be soft keys?

2. Which functions should be implemented with hard-wired function keys and which should be implemented with soft keys?

3. In some applications, it may be necessary to have more function keys active than are available on the keyboard. What is the most effective technique for handling this problem?

4. What techniques should be provided to help the user recover if the wrong function key is hit accidentally?

Use of Touch Panel Technology. The use of a touch panel has significant potential as a user input device. The primary concern with the use of touch panels for automated technical data systems has been durability. More durable touch panels are now becoming available. Research is needed to test and evaluate these panels for automated technical data system applications.

Use of Voice Recognition. Voice recognition has the potential to be very useful as an input device since it does not require the technicians to stop what they are doing, put down tools, and press keys to obtain the desired information. Significant advances are being made in voice input technology. Research is needed to test and evaluate these technologies for technical data applications.

Use of Voice Synthesis. The use of voice synthesis to present technical information may be valuable in those situations where it is difficult to locate the display where it can be easily viewed by the technician. It may also have an advantage for some technicians with limited reading skills. As with voice recognition, significant progress has been made in developing voice synthesis technology. Research is needed to test and evaluate these technologies for technical data applications.

Data Base Issues

Although the current project did not directly address the data base problem, several data base problems have been identified.

Neutral Data Base. The concept of a neutral data base has much inherent appeal. Although the neutral data bases have been developed with some success for printing applications, the concept has not been successfully demonstrated for use with automated technical data systems. Research is needed to test the concept and to identify its limitations.

Data Base Structure. Previous work has based the design of automated technical data bases on the design of current paper-based technical data. Thus, the data bases "mirror" the TO system. There are sections for theory of operation, system description, repair procedures, etc.--just as in the TO. There is a need to avoid the tendency to duplicate the TO system and develop a data design and a data base approach that is specifically designed for electronic applications. The primary concern should be whether all of the required information is in the data base and can be easily retrieved.

Portable System Memory Limitations. For at least the near future, it will not be possible to maintain the entire data base on one portable computer memory device. There are two basic approaches to resolving this problem: (a) divide the data base into smaller units and preload the data on several memory devices, or (b) load a memory device from a central data base with the

specific information required for the task to be performed. Each approach has advantages and disadvantages. Research is needed to evaluate the relative merits of each approach. In addition, each approach has several research issues which must be resolved before it can be effectively applied. The primary issue to be resolved for the preloading approach is how to partition the data base in a meaningful manner that will avoid duplication of data while limiting the number of cartridges that the technician must take to the job. The primary issue to be resolved for the custom loading approach is how to determine what information must be loaded so that the technician does not get to the job and find that the cartridge does not contain some essential information.

Other Issues

Portable System Use. Very little is known about the problems which will be encountered in using a portable automated technical data system on the flightline or a similar environment. There are a number of questions which require answers:

1. How will the portable system be used in the field?

2. What is the maximum distance from which the portable system display must be viewed? What problems are encountered in viewing the system?

3. Where should the system be placed for convenient use?

4. What lighting problems are encountered in using the system on the flightline? What are the limits of the lighting conditions under which the system will be used?

5. What are the maximum weight and maximum size acceptable for flightline use?

6. What are the actual power constraints? How often must the system operate on its own batteries? What is the minimum battery life required for operational use of the system on the flightline?

7. What problems are encountered in using memory cartridges on the flightline?

8. What features should be added to the portable system?

9. Are there any tasks that cannot be supported by the portable system?

10. Do technicians like to use the portable system on the flightline?

11. How should the portable system be used to support multiperson tasks?

12. What problems will be encountered in using voice recognition on the flightline?

Quality Control. Technical data for presentation on an automated system must be 100% accurate. Research is needed to develop quality control

procedures to ensure that the required accuracy is achieved. The primary area requiring research is the development of effective, yet practical, techniques to verify the accuracy of branching instructions and other coding instructions which control the order of presentation of the data. These instructions must be completely accurate to ensure that the user's request takes him where he wants to go and that screens composed of elements from different parts of the data base contain the data that they are supposed to contain (e.g., the correct text and graphics are linked together).

Comprehensive Evaluation. A comprehensive evaluation in which a complete set of data for an operational system is tested under realistic conditions is badly needed. The data should be developed using the coding and data development procedures that will be used in an operational application. The tests conducted thus far have been very limited in scope. They have been sufficient to demonstrate the feasibility and desirability of the basic concepts. However, they have not been sufficient in scope to test the full range of problems which may be encountered in a full-scale application. Such a test should be conducted before any operational application of an automated technical data presentation system is made.

Concluding Remarks

As indicated earlier, the research conducted in this project has demonstrated that automated technical data presentation systems are feasible. Further, it has demonstrated that a well-designed system will be accepted and used by technicians. In fact, the technicians who participated in the CMAS II tests were eager to see such a system implemented, and soon.

Although further research is needed to refine the technology and to develop the optimum system, the technology has progressed to the point that the development of applications of the technology to operational systems should be undertaken. The available evidence indicates that such a system has the potential to greatly improve the efficiency of the Air Force technical order system and maintenance operations.

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GLOSSARY

ABDA	Aircraft Battle Damage Assessment
ABDR	Aircraft Battle Damage Repair
AFHRL	Air Force Human Resources Laboratory
APS	Authoring and Presentation System
ATOS	Automated Technical Order System
AMS	Automated Maintenance System
CAMS	Core Automated Maintenance System
CPB	Consolidated Parts Breakdown
CRT	Cathode Ray Tube
EDM	Electronic Display Module
FEA	Front-End Analysis
FIND	Fault Identification by Nodal Dependency
FPJPA	Fully Proceduralized Job Performance Aid
FSCM	Federal Supply Code for Manufacturers
FTD	Field Training Detachment
IF	Intermediate Frequency
IFF	Identify Friend or Foe
IMIS	Integrated Maintenance Information System
IPB	Illustrated Parts Breakdown
JGM	Job Guide Manual
LRU	Line Replaceable Unit
LTTA	Logic Tree Troubleshooting Aid
MANOVA	Multiple Analysis of Variance
MDC	Maintenance Data Collection
MDIS	Maintenance Diagnostics Information System
MMI	Man/Machine Interface
NPRDC	Navy Personnel Research and Development Center
NTIPS	Navy Technical Information Presentation System
PCMAS	Portable Computer-based Maintenance Aids System
QA	Quality Assurance
SGML	Standard Generalized Markup Language
SMR	Source, Maintenance, and Recoverability
SRU	Shop Repairable Unit
TCTO	Time Compliance Technical Order
TO	Technical Order
UII	Unified Industries, Inc.

APPENDIX A: CMAS II USER'S GUIDE

The Computer-based Maintenance Aids System II (CMAS II) is a prototype automated system for the presentation of technical data for use by Air Force maintenance personnel. The system has been designed to test various concepts for the presentation of technical data on a computer display. Evaluation of the system will provide the basis for the design of a system for operational use.

SYSTEM HARDWARE

Grid Compass Computer, Model 1139   Grid Systems 10-MByte Hard Disk.

TECHNICAL DATA CONTENTS:

The CMAS II demonstration system contains the data required for the maintenance of the RT-728A Receiver-Transmitter. The information has been adapted from TO 12P4-2APX64-2 and TO 12P4-APX64-4. The system provides the following information:

- Theory of Operation (complete unit)
- Checkout and Analysis (selected sections)
- Maintenance instructions for the Coder module including:
  - Theory of Operation
  - Remove and Replace Procedures (selected procedures)
  - Troubleshooting Procedures (to circuit board)
  - Schematic Diagrams (each circuit board)
- Illustrated Parts Breakdown (selected portions)

FEATURES

Rapid Location of Information. The system provides three features which allow you to rapidly locate and call up a specific piece of information. They are:

Table of Contents: Information can be located and retrieved by selecting from a series of tables of contents.

Direct Access: You can go to any subsection or procedure by entering the direct access mode and typing in the exact title. Also, if you know the frame number, you can go directly to that frame by typing the number.

Options Menu. Each frame has an associated options menu. The options menu lists specific supplemental information (such as a schematic) which you may need to complete a task. For example, if you are performing a checkout of the transmitter module, the options frame will take you directly to the transmitter schematic or IPB information for the transmitter. The options form also provides an option to go to the table of contents or the direct access mode.

Job Guide Format. Instructions for maintenance procedures are presented in a Job Guide format. Step-by-step procedures are provided for each task. Illustrations of the referenced hardware are provided as appropriate for the experience level of the user.

Multiple Levels of Detail. The system provides maintenance instructions for procedural tasks at two levels of detail called "tracks." Nonprocedural information such as theory of operation is presented at one level of detail. The levels of detail are:

Track 1: Instructions presented at this level are least detailed. They are intended for use by technicians who work on the system daily and are fully qualified on it. The procedures provide only the information required by the experienced technician who knows the system well.

Track 2: Instructions presented at this level are the most detailed. These instructions are designed to provide the inexperienced technician with all of the information that he needs to do the task. They are intended for use by apprentice technicians with limited experience or by experienced technicians who are new to the system or have not worked on the system for some time.

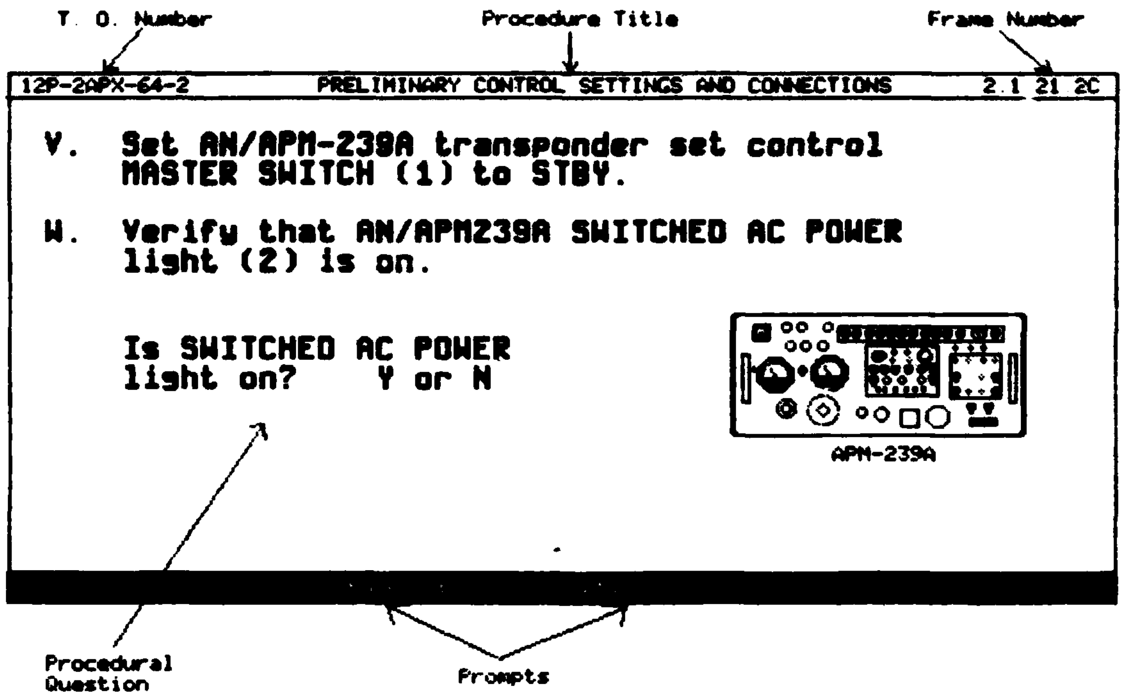
Pool Information. The system provides for quick access to a variety of support information such as theory of operation, schematic drawings, and parts information.

Beep. The computer will make a beeping sound if you enter a request that it cannot accept. This will happen if: (a) you press the wrong key (for example, C instead of B), (b) you make a selection which is not available (for example, you press the space bar to go to the next frame but the next frame option is not available), or (c) you enter a request by the direct access mode for information that is not in the system (for example, you enter the number of a frame that does not exist).

Scroll. Some drawings and illustrations required by the maintenance technician are too large to appear on the screen at one time. The system overcomes this problem by providing the capability to pan or scroll the illustration so that the drawing may be "moved" across the screen to view a different portion.

PRESENTATION FORMAT

The technical data are organized in a series of frames. A frame is the information presented at one time on the screen. Although several types of information may be presented in a frame, there are four pieces of information which are always present on the frame. They are the TO number, the title of the data presented, the frame number, and prompts. The basic layout of a typical frame is shown below.



STARTING THE SYSTEM

To operate the system:

1. Turn the hard disk on. The switch is located on the back of the unit in the upper right corner.

2. Turn the computer on. The switch is located on the back of the computer in the upper right corner.

After being turned on, the computer requires about 2 minutes to warm up, perform a self-test, and load the required software. The introductory frame will appear when the computer is ready for operation.

LOCATING AND RETRIEVING INFORMATION FROM THE SYSTEM

The CMAS provides two basic methods of locating a specific piece of information. Information may be located and retrieved by using a series of menus or by using the direct access method.

Table of Contents Method (menu method):

A series of Tables of Contents provide the basic method for locating information in the CMAS II. To locate data using the menu method:

1. Use the space bar to page forward to the main Table of Contents.

2. Select the section containing the desired information from the Table of Contents. Enter the number corresponding to the selection and press the code and return keys simultaneously. (Note: Enter the number only.) Do not put a space or any other character before or after the number. If you attempt

to enter a number not in the menu, the computer will respond "Invalid Request, Re-enter." If this happens, re-enter the number and press code/return.

3. A menu for the section of the data base will be displayed. Follow the same procedure to select the desired information.

4. At this point, the first frame of the desired technical data will be displayed, or a third menu will appear. The third menu provides a further breakdown of the technical information in that section from which you may choose.

Direct Access Method:

The direct access method allows you to go directly to a specific section of the technical data, provided that you know the exact title or the number of the first frame. It also allows you to go directly to any specific frame of information, provided that you know the frame number. This feature is useful if you stop work in the middle of a procedure and want to restart at the same place at a later time. To use the direct access method:

From start-up:

1. Use the space bar to page to the title page. Press D.

2. The direct access frame will appear. Type the name of the procedure or the number of the frame desired in the box and press the CODE and RETURN keys simultaneously. The name or frame number must be exactly correct. Do not add spaces or other characters before, after, or within the section title or number. If your entry is incorrect or the specified section or frame number does not exist in the data base, the computer will respond "Invalid Request, Re-enter." It will also give a "beeping" sound. If this happens, try again. If you make a typing mistake, use the backspace key to erase the characters you have typed.

From within the data base:

1. Press the "OP" key to select the options frame. Select "Direct Access Mode."

2. Follow the procedure described in 2 above.

USING THE SYSTEM

The CMAS II has been designed for simple operation. The following features are provided to simplify its use:

Prompt Line. The bottom line of each frame provides prompts which tell the user which options are available. The usual options are:

Next = Space Bar. If you press the space bar, the system will display the next logical frame.

Back = B. If you press B, the system will display the previous frame.

Option = O. If you press O, the system will go to the options frame.

Return = R. This prompt will appear only if you have branched from a procedure or subsection to another part of the data base (such as to a schematic). If you press R, the system will display the frame from which you branched to the current frame.

Note: You will note that some frames do not have an option of going to the next frame. The choice of the next frame is dependent upon the answer to a question asked in the text of the frame. In this case, the question and the options are listed in the frame. Answering the question will take you to the next logical frame.

Scroll. The scroll feature is used when a drawing or illustration is too large to fit on the screen. When the drawing is too large and scrolling is required, the scroll capability is made available to the user. When the scroll capability is active, the following symbol will appear:

The illustration is scrolled by using the arrow keys located on the right side of the keyboard. Pressing the left arrow causes the drawing to move to the left. Pressing the up arrow causes the drawing to move upward. Each press of an arrow key will move the schematics about 1/4 inch. If you press the code key and the arrow key at the same time, the schematic will move about 1/10 inch.

Scrolling is accomplished by using the arrow keys on the right side of the keyboard.

Illustrated Parts Breakdown (IPB).

The CMAS II is designed to provide rapid access to parts information. Two methods are provided for retrieving IPB information. This information can be obtained through the direct access method if you know the part number or reference designator number. If you do not know the part number or reference designator, you can locate the part on an illustration. To retrieve IPB information:

From the main Table of Contents:

1. Select Illustrated Parts Breakdown from the Table of Contents.

2. The IPB Table of Contents will appear.

3. If you know the part number or reference designator, select the direct parts information mode. If you do not know the part number or reference designator or wish to view the illustration, select the appropriate section of the unit.

4. If you use the direct parts information approach, the system will display an illustration of the equipment and a listing of the pertinent information on the subject part.

5. If you do not use the direct parts information approach, the system will display an illustration of the equipment. Two techniques are used to permit you to select information on specific parts illustrated. In some cases, access to specific information is provided from index numbers keyed to the illustration. In other cases, a part is selected by moving a cursor arrow to the part of interest on the drawing and pressing code return. The cursor arrow always starts at the lower right corner of the drawing. One press of the cursor will move the cursor about 1/4 inch. If you press the code and arrow key at the same time, the cursor will move about 1/10 inch. The system provides specific directions for each request.

EXERCISES FOR THE CMAS II USER'S GUIDE

Using the Table of Contents method, find the Theory of Operation explanation of Pulse Designations.

Using the Table of Contents method, find the preliminary operational check.

Using the Table of Contents method, find the Remove and Replace Instructions for the Coder Module.

Using the Direct Access method, find the Emergency Enable Check section of the Checkout Procedure. Call up the Options Form.

Use the Direct Access Method to find frame 2.8.3C. Use the Options Form to select More Detail.

From the Main Menu, select Illustrated Parts Breakdown. From the IPB Menu, select Direct Parts Information.

Using the Direct Parts Information method, find the part number for Reference Designator A5A1Q4.

Using the Direct Parts Information method, find the reference designator for Part Number 01A236508.

Using the Direct Access Method, select the Troubleshooting Procedures. Perform the following:

1. From the first frame, select Options Form.
2. From the Options Form, select Schematics.
3. From the Schematics Menu, select the Coder Module.
4. From the Coder Module, select board A5A1.
5. Use the arrow keys to scroll the schematic.
6. Locate the "MODE C A Enable."

APPENDIX B: CMAS II DEMONSTRATION OUTBRIEFS

Airman First Class - Low Experience

1. I want it to stay here. It is a lot faster than using the TO. You don't have to fumble through pages. You can go to exactly what you want.

2. You can find what you want right away. It is easier to read. The TO is harder to use because you lose your place and the print is smaller. With the computer you can tell exactly where you are. It must be easier to use because of the way it is displayed, because the data looks like it came right from the TO.

3. I really like the way the IPB works. I know how much time it would save me because it is my job to order parts.

4. There isn't anything I don't like about it. It is easy to operate and work from. What is there to not like? There isn't anything about it that is confusing.

5. One advantage to the TO schematic is that you can look at the whole thing at one time. I don't see any way out of it. If you made them small enough to fit on the screen, you wouldn't be able to read them. If you made the screen big enough, it would be too big.

Staff Sergeant (Quality Assurance Inspector) - High Experience

1. It simplifies things and is easy to use.

2. Only question is more detail. A technician can think he knows everything and leave a step out. Questions whether or not technician should have option of choosing less detailed level. I left a cable off using less detail.

3. This would force people to use TOs more. They can open a book and leave it to the right page, but if the computer stays on one frame very long, they're not using it and supervisors can spot it quickly.

4. Schematics were unclear around bottom edges. Were too crunched up to really tell where a signal or test point was.

5. Don't feel that instructions on using test equipment (oscilloscope, etc.) should be part of regular checkout. Should have separate cartridges (or disks or whatever) on how to use different test equipment available to teach with, but anyone working on the system should already know how to use the equipment.

6. Would be very helpful to have automatic interconnection between related schematics. Scroll off one and onto the next appropriate one for desired signals.

7. Two direct access methods were confusing. Didn't always know which one you were in.

8. Liked troubleshooting procedures best of all. There is a real need for accurate troubleshooting after determining which module is bad.

9. Would definitely like to see similar system incorporated into USAF. System would help a person become a better troubleshooter and technician if the person wanted to learn from the system and not be a slave to the computer. Training and normal troubleshooting procedures should not be together in the same system.

Airman First Class - High Experience

1. With practice it would be great. The IPB is real nice. I like it a lot.

2. It is hard to find things on the schematic. With the TO you can look at the whole thing. You could get the job done with the computer but it wouldn't be as convenient.

3. The computer is easy to use. You can use it with just a few minutes practice without any problem at all. I've never had any experience with computers and I can't type but I didn't have any problem using it.

4. The way that information is presented makes it easy to use. The checklist layout with the different levels makes it easy to read. The drawings which point out the location of knobs and connectors make it easy to use.

5. I would like to have more items per frame. Just having a few items makes it a little slow.

6. It is pretty convenient to use. It isn't much bigger than the TO. It is easy to get lost on a TO page. With the computer, everything is right there. You can't get lost. This makes it real nice.

7. I would like to see the system have battery power.

8. I would like to see it implemented in the Air Force. It would be great for changes.

Airman First Class - Low Experience

1. I like it. I have a very positive reaction to it. You can get information a lot faster once you become acquainted with the system. It sure beats flipping through the pages of a TO.

2. It would be very easy to make changes to the technical data if there is anything wrong with the information in the system.

3. Once the bugs are out, it will be a very good troubleshooting aid. It does in fact tell you what to do next. It would speed up your troubleshooting time. I don't know if that is good or bad. It would make troubleshooting so simple that anyone could do it with limited training. I guess it would be good for the Air Force.

4. The system could have a lot larger screen for reading schematics. It would give more detail and make it easier to locate things on the schematic. A 12 to 14 inch diagonal screen would sure help. You don't need a larger screen except for reading schematics. The screen on this computer is big enough for everything else.

5. The screen is easily readable.

6. I can't think of anything else I have against it. All in all it is a pretty good system.

7. It is great for looking up part numbers. Just to be able to put all of the parts information on the screen so quickly is incredible. It saves a good 5 to 10 minutes.

8. I would like to see it implemented in the Air Force. I think we will always have TOs in book form. There will always be books sitting on the shelf. Computers can lose information. It might be possible to replace TOs with a computer if there is a way to keep from losing information (such as from magnetic fields).

Airman First Class - High Experience

1. The computer is very fast. It is much easier to use than the TO.

2. When you go through the checkout, you must read every step. It is easy to skip over a step in the TO. With the computer you are not as likely to skip over a step.

3. I like being able to go to the table of contents and go anywhere (in the data base) I want to go. It is easy to get where you want to go. If I used the computer a lot, I probably wouldn't get lost. It is easy to move around and get where you want to go.

4. The graphics were really neat. The way they point to a component makes it easier to find things.

5. Using the computer was fun - a lot more interesting than the stupid TO.

6. I didn't like the schematics. It is neat to be able to scroll but it is not like having the whole thing in front of you. You could use the schematics after awhile though.

7. I would like to see the computer put on a caddy like you use for an O-scope so that I could set it beside me and move it wherever I want to.

8. The screen needs a tilt lock to keep it in place.

9. I would like to see the computer implemented in the Air Force. I thought it was a joke at first but now I think it will work. I liked using it.

Airman First Class - Low Experience

1. I like it a whole lot better than TOs. It is a whole lot easier not to skip steps with the computer. It is easier because you don't get lost. A lot of times the TO page will flip while you are doing something. Then you have to find where you were again. With the computer you stay right where you were.

2. I like the IPB a lot. It saves a lot of time. Especially when you go to get information on a component. You have everything you need right there and don't have to go to a file (microfiche file) to get part of it.

3. The notes and cautions are good. A lot of times you tend to skip over them in the TO. If they are on the screen, you go ahead and read them.

4. I liked having both levels of detail. I used both levels but preferred the more detailed level. I liked the illustrations too. They tell you exactly where to put the connections. They are especially good for people who have not gone through the procedure before.

5. I liked the troubleshooting too. It is a whole lot more specific. Plus, it worked.

6. There isn't anything that I didn't like about it. I don't have any suggestions for redesigning it.

7. I would like to see it implemented in the Air Force.

Staff Sergeant (FTD Instructor) - High Experience

1. There is a world of difference between the computer and the TO.

2. The computer is so easy to use. It formats things and limits the amount of information that you see at a time, which limits the confusion. It puts information in a step-by-step format which is easy to follow.

3. With the TO you have the problem of the pages being open and having to look back and forth and maybe missing a step in the procedure. With this it is impossible, almost.

4. The IPB is an outstanding example of what the computer can do. You can put in a part number and it spits the information right out to you. That's excellent.

5. It could be extremely useful in training. The procedures outline the process logically. The simplicity of the information makes it ideal for training. The way information is formatted in the TO you have to go from section to section and try to find it.

6. I especially liked the operational checkout and the IPB.

7. At first I didn't like the schematics because they show such a limited view but after a little familiarization it seems that they may not be as good as the TO but they are sufficient.

8. I don't see anything I could do to improve it.

9. As an instructor and a technician I think the system is ideal. It facilitates much quicker and more precise maintenance. I kind of regret that it can't be here tomorrow. It is an ideal way to go.

Senior Airman (Inertial Navigation Shop) - No Experience

1. I thought it was pretty easy to use. The program setup itself I thought was fantastic.

2. I thought it was pretty easy following the procedure on the computer. There were some parts I had trouble with, but it didn't take long to figure out how to do it by going to the schematics and troubleshooting procedures. It is a real easy system to use.

3. I liked the scrolling on the schematics. I think it was a lot faster than trying to use the TO where you have to pull out the pages. It was easier to use than the TO. It was easy to push the button and trace the wiring as it flows by. You don't get lost tracing a signal.

4. It is an easy system.

5. This was totally a lot faster than the TO. This will expedite troubleshooting and system checkout.

6. I went through the theory of operation and got a general idea. If I had been reading the TO, I probably would have been bored to death. I didn't get tired reading or anything.

7. I sure would like to see it implemented in the Air Force.

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